USAARL Report No. 2015-01

Assessment of Four Passive Hearing Protection Devices for Continuous Noise Attenuation, Impulsive Noise Insertion Loss, and Auditory Localization Performance

By Robert Williams
JR Stefanson
Efrem Reeves
Elmaree Gordon

United States Army Aeromedical Research Laboratory

Auditory Protection and Performance Division

November 2014

REPORT DOCUMENTATION PAGE			*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
17/11/2014	Final	

4. TITLE AND SUBTITLE
Assessment of Four Passive Hearing Protection Devices for Continuous Noise Attenuation, Impulsive Noise Insertion Loss, and Auditory Localization Performance

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Robert Williams
JR Stefanson
Efrem Reeves
Elmaree Gordon

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Aeromedical Research Laboratory
P.O. Box 620577
Fort Rucker, AL 36362

8. PERFORMING ORGANIZATION REPORT NUMBER
USAARL 2015-01

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Marine Corps Systems Command
2200 Lester Street, Bldg 2202
Quantico, VA 22134-6050

10. SPONSOR/MONITOR'S ACRONYM(S)
USMC

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT
The report covers the results of testing four passive hearing protection devices for continuous noise attenuation using the Real Ear Attenuation at Threshold (REAT) test, the Impulsive Noise Insertion Loss (IPIL) test, and for localization performance using a free-field localization test. Tests generally showed more attenuation with solid plugs (as opposed to vented plugs), greater IPIL with solid plugs, and conflicting localization performance results.

15. SUBJECT TERMS
hearing protection, impulse noise, REAT

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Loraine St. Onge, PhD
					19b. TELEPHONE NUMBER *(Include area code)*
UNCLAS	UNCLAS	UNCLAS	SAR	60	334-255-6906

Reset

This page intentionally left blank.

Table of contents

Table of contents (continued)

List of figures

List of figures (continued)

Table of contents (continued)

List of figures (continued)

Page

List of tables

Table of contents (continued)
List of tables (continued)

Page

This page intentionally left blank.

Introduction

Men and women serving in the armed forces are routinely exposed to high levels of both impulsive and continuous noise. If Soldiers are unprotected, this noise exposure may lead to temporary or permanent changes in hearing sensitivity called threshold shifts. Temporary and permanent threshold shifts among Soldiers can negatively impact Soldiers' ability to perform their duties, and may decrease the future standard of living and career opportunities for the Soldier. Tinnitus and noise-induced hearing loss are the two most prevalent disabilities for individuals who have served in the military (U.S. Department of Veteran's Affairs, 2012).

Use of hearing protection devices (HPDs) may cause difficulties in auditory perception. The attenuation of sound that provides protection from intense noise also attenuates quiet sounds, and can make verbal communication difficult without raising one's voice. Additionally, HPDs alter an individual's head-related transfer function, and may degrade an individual's ability to determine the direction of a sound source. The ability to determine the direction of a sound source only through auditory cues is a process referred to as auditory localization, or simply localization. As a result, Soldiers may go unprotected from loud noises, even when it is reasonable to anticipate hazardous noise exposure.

Recent advances in hearing protector technology have been aimed at correcting some of these issues. So-called passive non-linear hearing protection devices have been created. These devices have a very narrow acoustic vent through the plug. The manufacturers of these devices claim that these vents allow low-level sounds to pass through the plug, but attenuate louder impulsive sounds. The attenuation of impulsive noises typically varies as a function of both the peak pressure level and the frequency content of the noise (Murphy et al., 2011).

Determination of acceptable HPDs for military users depends on the characteristics of the devices, and the needs of the end user. This report details the tests of four passive HPDs in terms of continuous and impulsive noise attenuation, and change in localization ability when using the devices.

Study objectives

The objective of this study was to measure performance characteristics of four different hearing protection devices: the Moldex BattlePlug®, the 3M™ Combat Arms Earplug™ (dual ended version), the Etymotic EB-15 BlastPLG™, and the Surefire EP4® earplug. These tests were sponsored by the U.S. Marine Corps Systems Command. The sponsor selected the devices to be tested, and specified testing only the passive properties of the devices. The characteristics measured were the continuous noise attenuation (measured by Real-Ear-Attenuation at Threshold [REAT] test), the impulsive peak insertion loss (IPIL) (measured by acoustic test fixture methods defined in ANSI 2010), and the localization error (measured using a free field localization test).

System description

The Moldex BattlePlug® is a pre-formed, triple-flanged, passive non-linear earplug. The plug contains vents which may be opened to attenuate impulsive noise, or closed to attenuate all sound. It is available in three sizes (small, medium, and large). Figure 1 shows the Moldex BattlePlug® (Moldex).

Figure 1. Moldex BattlePlug® (Moldex).

The Combat Arms Earplug™ is a pre-formed, triple-flanged earplug manufactured by 3M™. The double ended version was tested in this study. The double-ended Combat Arms plug has a yellow-colored, vented end designed to attenuate impulsive noise, and a green-colored, solid end designed to attenuate all sound. The version used for these tests is available in one size. There are newer versions of the combat arms ear plug, which were not evaluated. Figure 2 shows the double ended Combat Arms Earplug™ (3M).

Figure 2. Combat Arms Earplug™ (3M).

The Etymotic EB-15 BlastPLG™ is an electronic earplug manufactured by Etymotic Research, Inc. The behavior of the plug is similar to the performance of the non-linear electronic devices described in the introduction. It uses a compression circuit to attenuate loud noises, and has a high gain setting to amplify quiet sounds. It does not feature active noise reduction circuitry. The ear tips of the device are interchangeable. For these tests, all of the measurements were made with the electronics in the device turned off, and dead batteries were placed in the device to maintain normal weight and density. This configuration was specified by the sponsor. Two different types of ear tips were tested: foam ear tips (available as a small or large tip), and triple-flanged ear tips (available as a small or large tip). Figure 3 shows the Etymotic EB-15 BlastPLG™, along with several different ear tips (not all of the ear tips shown were tested) (Etymotic Research, Inc).

Figure 3. Etymotic EB-15 BlastPLG™ and ear tips (Etymotic).

The EP4® is a pre-formed, triple-flanged, passive non-linear earplug manufactured by Surefire. The vents in the plug may be opened to attenuate impulsive sounds, or closed to attenuate all sound. The EP4® features a retention system that fits in the concha region of the pinna. The plug is available in three sizes (small, medium, and large). Figure 4 shows the Surefire EP4® (Surefire).


Figure 4. Surefire EP4® (Surefire).

Methods

Participant selection and screening

This project was conducted as a test (not research), after determination by the USAARL Regulatory Compliance office. Volunteers did not sign an informed consent document; however they were given a test information sheet, and told that they could withdraw from the test at any time.

All of the participants (*n=35*) in these tests were volunteers over the age of 18. Both active military and civilians were allowed to participate. Demographic information (age, gender, etc.) of the test participants was not recorded.

Prior to participating in these tests, volunteers were screened for normal hearing thresholds by pure tone audiogram at 125, 250, 500, 1000, 2000, 4000, and 8000 hertz [Hz]. Volunteers were not accepted for participation if their thresholds at any test frequency were more than 25 dB hearing level. Volunteers were also given an otoscopic examination, and were not allowed to participate if this examination revealed excess ear-wax, irritation or injury to the ear canal or tympanic membrane, or anatomical abnormality that would prevent the use of the devices being tested. Volunteers were given a questionnaire to report if they were sick, suffering from allergies, experiencing tinnitus, or otherwise in poor health. Those that reported symptoms were not allowed to participate in the tests, or were asked to return when no longer experiencing symptoms. Not all participants completed all of the tests with each device.

Continuous noise attenuation – REAT testing

Continuous noise attenuation was measured using REAT (Method A) described in ANSI S12.6-2008 "Methods for Measuring the Real-Ear Attenuation of Hearing Protectors". The REAT test requires the measurement of a participant's audiometric threshold in a diffuse sound field with no HPD in place, and then measuring the participant's thresholds in the same sound field while wearing the HPD under test (ANSI, 2008). The tests were completed in a double-walled acoustic enclosure located in the USAARL Acoustics building. The test was conducted using the VI Acoustics REAT Plus software, and the sound field was calibrated using the VI Acoustics Trident software.

For each threshold measurement, the participant was seated in the sound chamber, and given a thumb switch. One-third octave band filtered noise, with the center frequency set at the current test frequency, was produced in the room. The noise pulsed (increasing and decreasing in volume from inaudible to the test level) at a rate of 2 times per second. The noise decreased in level when the thumb switch was held, and increased in level when the thumb switch was released. The participant was instructed to press and hold the thumb switch when the noise was audible, and release the thumb switch as soon as the sound became inaudible. The test level of the noise was tracked in time, and the level at which the switch was either pressed or released (called a reversal) was tracked. The test continued at a given frequency until 6 reversals within 6 dB of each other were tracked for that frequency. The level at each of these reversals was averaged to determine a threshold at that test frequency (ANSI, 2008).

The test continued for all frequencies being tested. For these tests, the frequencies tested were 125, 250, 500, 1000, 2000, 4000, and 8000 Hz. Prior to testing any device, participants were required to complete a minimum of five open ear threshold measurements as training in the REAT test procedure. The last three of these threshold measurements were required to produce variation of no more than 6 dB at any test frequency (ANSI, 2008).

After completing the training thresholds, the participant then completed four test thresholds for each device: two open ear thresholds, and two occluded thresholds (i.e. while wearing the HPD under test). The average difference between the open and occluded thresholds for each device was calculated as the attenuation of the device for that participant (ANSI, 2008).

Twenty participants tested each device in both configurations (vented and un-vented for the passive plugs, flanged, and foam ear tips for the EB-15s). Some participants tested multiple devices.

Localization testing – free field localization test

The localization testing was completed in the anechoic chamber located in the Acoustics section of USAARL. The test required the participant to determine the location of a loudspeaker playing a burst of white noise. The loudspeaker was moved using a robotic arm to 12 different azimuth locations equally distributed on a circle around the participant's head. To prevent the participant from determining the location of the loudspeaker visually, the test was performed with no lights turned on in the anechoic chamber. The participant's response was recorded using a stylus and spherical interface. The participant would use the stylus to point to the location on the sphere that corresponded to the location of the loudspeaker relative to their head. This test method was based on a similar test conducted at the Air Force Research Laboratory (Gilkey et al, 1995).

For each device, the participant completed three iterations of the test: one with no HPD in place, and one in each of the two configurations of each device (vented and un-vented for the passive plugs; flanged and foam ear tips for the EB-15 earplugs). The 12 points were presented in a random order for each test. Some participants tested more than one device.

Once the tests were completed, the error, or the absolute difference between the actual azimuth and the participant's response, was calculated for each test point. The average of the error values for each test was calculated. Additionally, each response for each test was determined to be either correct (when the azimuth guess was within plus or minus 15 degrees of the actual azimuth), or incorrect (when the azimuth guess was outside plus or minus 15 degrees of the actual azimuth). The percentage of correct responses was calculated for each test.

Impulsive noise insertion loss

The impulsive noise tests were performed using the methods given in ANSI S12.42-2010 "Methods for the Measurement of Insertion Loss of Hearing Protection Devices in Continuous or Impulsive Noise Using Microphone-in-Real-Ear or Acoustic Test Fixture Procedures." The source of impulse noise used was the USAARL Acoustics Branch 6 inch shock tube. The shock tube generates impulsive noises using compressed air. A membrane of paper, aluminum foil, or Mylar is placed over the open end of a pressure vessel, which is sealed against the barrel of the shock tube using a hydraulic ram. The pressure vessel is then pressurized until the membrane bursts, sending a shock wave down the tube and into the exposure area. By varying the placement of the ATF and the type of membrane used, it is possible to vary the strength of the shock wave at the test location.

ANSI S12.42 calls for three free-field peak levels of impulses: 166 to 170 dB, 148 to 152 dB, and 130 to 134 dB, all with an A-duration between 0.5 and 2 milliseconds (ms). This series of tests only included shots at peak levels of 166 dB and 150 dB. Two headforms were used simultaneously to speed up the test process, with a single free field probe located between the two headforms. Six calibration shots at each peak level were measured with no HPD present (actual unprotected shots), and the transfer function between the probe and each 'ear' of the manikin was calculated. The transfer functions were then averaged for each 'ear' of each ATF. Next, the manikins were fitted with the HPD under test, and additional impulses with the same peak level were recorded (protected shots). Using the transfer functions from the actual unprotected shots and the free field probe measurement from the protected shots, an estimated unprotected signal was calculated for each ear of both ATFs for the protected shots. The IPIL was calculated as the difference (in decibels) between the peak from the estimated unprotected signals and the peak from the protected signals (ANSI, 2010).

During the test, five samples of the Combat Arms Earplug™, six samples of the BattlePlug®, and nine samples of the EP4® were used for testing. The intention was to use five samples for each device, but four samples of the EP4® and one sample of the BattlePlug® were damaged while either inserting or extracting them from the ATF. This damage was expected to compromise the protector, and the damaged samples were replaced for the next fitting. Only four samples of the EB-15 were provided, so only four were tested.

Nominally, each hearing protector sample was fitted to each manikin once (two fittings per sample), but when a sample was damaged, the replacement was only fit once. Two shots were recorded for each fitting. For all calculations (transfer functions and IPIL measurements), all of the pressure vs. time data was windowed from 10 ms prior to the peak (in the free field measurement), to 300 ms after the peak, using a rectangular window. The IPIL measurements for each ear, shot, sample, and fitting were averaged into a single value for each protector configuration and peak level. In the test results, the number of points averaged is specified.

Results

Continuous noise attenuation

Figures 5 and 6 show the continuous noise attenuation provided by the devices tested in this study. Figure 5 shows the average attenuation provided by the three vented plugs, while figure 6 shows the average attenuation provided by the five solid plugs. Error bars indicate ±1 standard deviation. Data from each test is tabulated in the appendix.

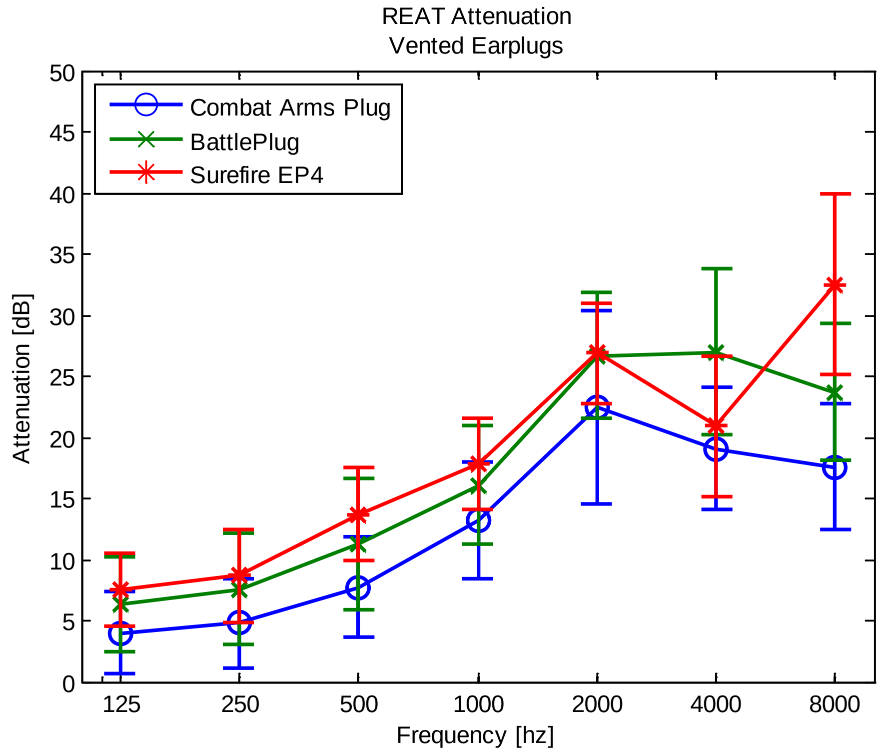

Figure 5. Vented plug REAT attenuation.

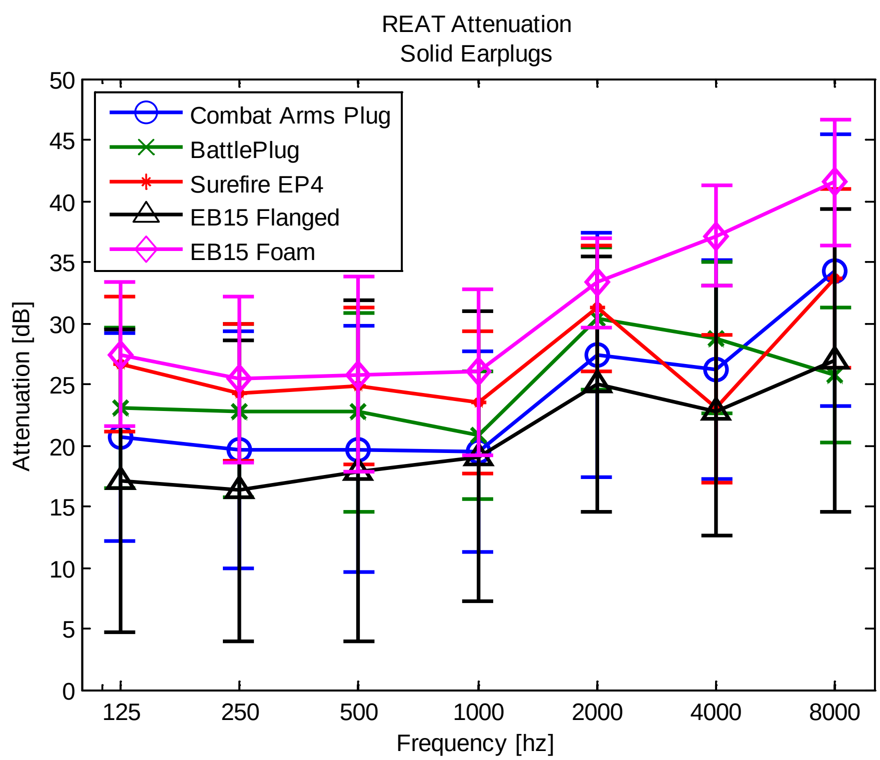

Figure 6. Solid plug REAT attenuation.

Localization testing

Tables 1 through 4 give the mean error (in degrees) and percent of correct responses for each test for the hearing protective devices examined in this study. They also show the average values of the mean error and percent of correct responses for each device. Individual test results are plotted in the appendix.

Table 1.
BattlePlug® localization results.

Test number	Open Ear mean error	Open Ear % correct	Vented mean error	Vented % correct	Closed mean error	Closed % correct
1	17.28	58.33%	17.52	50.00%	18.16	50.00%
2	44.72	58.33%	51.97	33.33%	48.71	25.00%
3	32.73	50.00%	38.87	41.67%	34.78	50.00%
4	27.55	50.00%	41.66	50.00%	33.49	50.00%
5	14.10	50.00%	16.39	66.67%	17.47	50.00%
6	8.84	91.67%	54.43	41.67%	43.51	50.00%
7	16.63	50.00%	25.36	25.00%	44.14	41.67%
8	34.62	41.67%	39.14	16.67%	31.67	33.33%
9	27.31	41.67%	29.55	33.33%	20.24	50.00%
10	25.13	50.00%	32.74	25.00%	10.52	83.33%
Average Value	24.89	54.17%	34.76	38.33%	30.27	48.33%
Standard Deviation	10.87	14.30%	13.00	14.80%	13.09	15.11%

Table 2.
Combat Arms Earplug™ localization results.

Test number	Open Ear mean error	Open Ear % correct	Vented mean error	Vented % correct	Closed mean error	Closed % correct
1	30.32	50.00%	30.13	66.67%	51.47	25.00%
2	11.74	75.00%	19.69	58.33%	16.00	66.67%
3	12.97	66.67%	13.68	58.33%	61.34	16.67%
4	7.14	100.00%	43.24	41.67%	44.92	33.33%
5	38.25	41.67%	37.12	25.00%	36.02	25.00%
6	32.44	41.67%	13.37	75.00%	36.04	50.00%
7	19.44	50.00%	15.77	58.33%	20.96	66.67%
8	21.76	33.33%	26.39	41.67%	32.66	16.67%
9	27.98	50.00%	29.03	50.00%	35.42	58.33%
10	27.91	41.67%	41.82	33.33%	39.89	25.00%
Average Value	22.99	55.00%	27.02	50.83%	37.47	38.33%
Standard Deviation	10.10	20.11%	11.27	15.44%	13.30	20.11%

Table 3.
Etymotic EB-15 localization results.

Test number	Open Ear mean error	Open Ear % correct	Flanged mean error	Flanged % correct	Foam mean error	Foam % correct
1	18.12	33.33%	15.00	41.67%	20.07	50.00%
2	12.70	75.00%	37.56	50.00%	33.96	58.33%
3	25.12	75.00%	16.71	50.00%	25.63	50.00%
4	36.37	25.00%	39.06	25.00%	34.52	33.33%
5	15.98	50.00%	24.60	58.33%	47.29	33.33%
6	41.51	41.67%	21.50	33.33%	18.68	50.00%
7	16.20	50.00%	37.12	33.33%	11.95	58.33%
8	21.26	41.67%	31.01	41.67%	24.40	50.00%
9	42.14	16.67%	36.95	33.33%	61.73	16.67%
10	48.78	33.33%	50.13	50.00%	62.68	25.00%
Average Value	27.82	44.17%	30.96	41.67%	34.09	42.50%
Standard Deviation	13.14	19.26%	11.25	10.39%	17.78	14.41%

Table 4.
Surefire EP4® localization results.

Test number	Open Ear mean error	Open Ear % correct	Vented mean error	Vented % correct	Closed mean error	Closed % correct
1	28.04	33.33%	39.05	25.00%	27.83	50.00%
2	17.13	58.33%	35.83	58.33%	15.89	50.00%
3	46.34	50.00%	25.00	41.67%	32.29	25.00%
4	35.39	58.33%	36.34	41.67%	19.83	50.00%
5	27.26	66.67%	37.20	50.00%	33.82	25.00%
6	28.73	50.00%	85.91	8.33%	59.81	25.00%
7	54.17	33.33%	53.02	33.33%	46.06	50.00%
8	40.86	58.33%	26.00	25.00%	35.84	50.00%
9	51.50	50.00%	52.19	33.33%	58.41	50.00%
10	25.29	58.33%	25.90	66.67%	17.98	41.67%
Average Value	35.47	51.67%	41.64	38.33%	34.78	41.67%
Standard Deviation	12.30	10.97%	18.43	17.21%	15.75	11.79%

Impulsive noise insertion loss

Tables 5 through 20 give the results of the IPIL testing. Each table contains mean and standard deviation of the peak pressure level and the A-duration of the wave (as recorded by the free field probe) for the set of shots used to measure each HPD, as well as the number of measurements used to calculate these values. Also included is the difference between the measured and estimated peak of the six unprotected calibration shots for each ear of both ATFs (in dB). Finally, the mean IPIL and the standard deviation of IPIL values for each HPD configuration at the listed peak pressure level are given, as well as the number of measurements used to calculate those values.

Table 5.
BattlePlug® unvented 150 dB peak IPIL

Free Field Pressure Data [*N = 16*]			
Mean Peak		151.5 dB	
Peak Standard Deviation		0.4 dB	
Mean A-duration		0.86 ms	
A-duration Standard Deviation		0.01 ms	
Difference between measured and estimated calibration shot peaks [dB]			
ATF 1 Right Ear	ATF 1 Left Ear	ATF 2 Right Ear	ATF 2 Left Ear
-0.1	0.1	-0.1	-0.1
-0.1	0.0	0.0	0.1
-0.2	0.0	-0.1	-0.1
0.1	-0.2	0.0	0.0
0.1	-0.1	0.2	0.2
0.1	-0.2	0.0	0.0
Impulsive Peak Insertion Loss [*N = 40*]			
Mean IPIL		38.9 dB	
IPIL Standard Deviation		3.2 dB	

Table 6.
BattlePlug® vented 150 dB peak IPIL.

Free Field Pressure Data [*N = 16*]			
Mean Peak		151.3 dB	
Peak Standard Deviation		0.4 dB	
Mean A-duration		0.86 ms	
A-duration Standard Deviation		0.01 ms	
Difference between measured and estimated calibration shot peaks [dB]			
ATF 1 Right Ear	ATF 1 Left Ear	ATF 2 Right Ear	ATF 2 Left Ear
0.0	0.0	0.0	0.0
-0.1	-0.1	-0.1	-0.1
0.0	0.0	-0.1	-0.1
0.0	0.0	0.2	0.2
0.1	0.1	0.0	-0.1
0.0	0.0	-0.1	-0.1
Impulsive Peak Insertion Loss [*N = 40*]			
Mean IPIL		31.1 dB	
IPIL Standard Deviation		2.8 dB	

Table 7.
BattlePlug® unvented 166 dB peak IPIL.

Free Field Pressure Data [*N = 16*]			
Mean Peak		165.5 dB	
Peak Standard Deviation		0.2 dB	
Mean A-duration		1.18 ms	
A-duration Standard Deviation		0.01 ms	
Difference between measured and estimated calibration shot peaks [dB]			
ATF 1 Right Ear	ATF 1 Left Ear	ATF 2 Right Ear	ATF 2 Left Ear
0.0	-0.4	0.0	0.0
0.1	-0.3	0.0	0.0
0.0	-0.4	-0.1	-0.2
-0.2	0.1	0.0	0.0
-0.2	0.1	0.0	0.0
-0.3	0.1	0.0	0.0
Impulsive Peak Insertion Loss [*N = 40*]			
Mean IPIL		39.1 dB	
IPIL Standard Deviation		3.8 dB	

Table 8.
BattlePlug® vented 166 dB peak IPIL.

Free Field Pressure Data [*N = 16*]			
Mean Peak		165.4 dB	
Peak Standard Deviation		0.3 dB	
Mean A-duration		1.18 ms	
A-duration Standard Deviation		0.01 ms	
Difference between measured and estimated calibration shot peaks [dB]			
ATF 1 Right Ear	ATF 1 Left Ear	ATF 2 Right Ear	ATF 2 Left Ear
0.0	0.1	0.0	0.0
-0.2	-0.1	-0.1	0.0
-0.1	0.0	0.0	0.0
0.0	-0.1	0.0	-0.1
0.0	-0.1	0.0	0.0
0.0	-0.1	0.0	-0.1
Impulsive Peak Insertion Loss [*N = 40*]			
Mean IPIL		33.9 dB	
IPIL Standard Deviation		2.5 dB	

Table 9.
Combat Arms Earplug™ unvented 150 dB peak IPIL.

Free Field Pressure Data [*N = 16*]			
Mean Peak		151.7 dB	
Peak Standard Deviation		0.2 dB	
Mean A-duration		0.85 ms	
A-duration Standard Deviation		0.01 ms	
Difference between measured and estimated calibration shot peaks [dB]			
ATF 1 Right Ear	ATF 1 Left Ear	ATF 2 Right Ear	ATF 2 Left Ear
0.0	-0.2	0.0	0.0
0.1	-0.1	0.0	0.0
0.1	-0.2	0.0	0.0
-0.1	0.1	0.0	0.0
-0.1	0.1	0.1	0.1
-0.1	0.1	0.0	0.0
Impulsive Peak Insertion Loss [*N = 40*]			
Mean IPIL		38.7	
IPIL Standard Deviation		2.9	

Table 10.
Combat Arms Earplug™ vented 150 dB peak IPIL.

Free Field Pressure Data [*N = 16*]			
Mean Peak		151.7 dB	
Peak Standard Deviation		0.3 dB	
Mean A-duration		0.85 ms	
A-duration Standard Deviation		0.01 ms	
Difference between measured and estimated calibration shot peaks [dB]			
ATF 1 Right Ear	ATF 1 Left Ear	ATF 2 Right Ear	ATF 2 Left Ear
0.0	0.0	0.0	-0.1
0.0	0.0	-0.1	0.0
0.0	0.0	0.0	-0.1
0.0	0.0	0.1	0.1
-0.1	-0.1	0.0	0.0
0.1	0.1	0.0	0.0
Impulsive Peak Insertion Loss [*N = 40*]			
Mean IPIL		29.4 dB	
IPIL Standard Deviation		0.7 dB	

Table 11.
Combat Arms Earplug™ unvented 166 dB peak IPIL.

Free Field Pressure Data [*N = 16*]			
Mean Peak		165.6 dB	
Peak Standard Deviation		0.2 dB	
Mean A-duration		1.18 ms	
A-duration Standard Deviation		0.01 ms	
Difference between measured and estimated calibration shot peaks [dB]			
ATF 1 Right Ear	ATF 1 Left Ear	ATF 2 Right Ear	ATF 2 Left Ear
-0.2	-0.1	0.0	0.0
-0.1	0.0	-0.1	-0.1
-0.1	0.0	-0.1	-0.1
0.0	-0.1	0.0	0.0
0.0	0.0	0.0	0.0
0.1	0.0	0.0	0.0
Impulsive Peak Insertion Loss [*N = 40*]			
Mean IPIL		38.0 dB	
IPIL Standard Deviation		5.4 dB	

Table 12.
Combat Arms Earplug™ vented 166 dB peak IPIL.

Free Field Pressure Data [*N = 16*]			
Mean Peak		165.4 dB	
Peak Standard Deviation		0.2 dB	
Mean A-duration		1.18 ms	
A-duration Standard Deviation		0.01 ms	
Difference between measured and estimated calibration shot peaks [dB]			
ATF 1 Right Ear	ATF 1 Left Ear	ATF 2 Right Ear	ATF 2 Left Ear
0.0	-0.1	0.0	0.0
0.0	0.0	-0.1	-0.1
0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0
-0.1	-0.1	0.0	0.0
-0.1	0.0	0.0	0.0
Impulsive Peak Insertion Loss [*N = 40*]			
Mean IPIL		34.1 dB	
IPIL Standard Deviation		1.1 dB	

Table 13.
EB-15 foam Tip 150 dB peak IPIL.

Free Field Pressure Data [*N = 14*]			
Mean Peak		151.4 dB	
Peak Standard Deviation		0.4 dB	
Mean A-duration		0.85 ms	
A-duration Standard Deviation		0.01 ms	
Difference between measured and estimated calibration shot peaks [dB]			
ATF 1 Right Ear	ATF 1 Left Ear	ATF 2 Right Ear	ATF 2 Left Ear
0.0	0.0	0.0	0.0
-0.1	0.0	-0.1	-0.2
0.0	0.1	-0.1	-0.1
0.0	0.0	0.0	0.0
0.1	0.0	0.1	0.2
0.0	-0.1	0.1	0.0
Impulsive Peak Insertion Loss [*N = 32*]			
Mean IPIL		48.1 dB	
IPIL Standard Deviation		1.8 dB	

Table 14.
EB-15 flanged Tip 150 dB peak IPIL.

Free Field Pressure Data [*N = 14*]			
Mean Peak		151.6 dB	
Peak Standard Deviation		0.3 dB	
Mean A-duration		0.85 ms	
A-duration Standard Deviation		0.01 ms	
Difference between measured and estimated calibration shot peaks [dB]			
ATF 1 Right Ear	ATF 1 Left Ear	ATF 2 Right Ear	ATF 2 Left Ear
-0.1	-0.1	0.1	0.1
0.1	0.1	-0.1	-0.1
-0.1	0.0	0.0	-0.1
0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0
Impulsive Peak Insertion Loss [*N = 32*]			
Mean IPIL		42.2 dB	
IPIL Standard Deviation		2.2 dB	

Table 15.
EB-15 foam Tip 166 dB peak IPIL.

Free Field Pressure Data [*N = 14*]			
Mean Peak		165.7 dB	
Peak Standard Deviation		0.1 dB	
Mean A-duration		1.18 ms	
A-duration Standard Deviation		0.00 ms	
Difference between measured and estimated calibration shot peaks [dB]			
ATF 1 Right Ear	ATF 1 Left Ear	ATF 2 Right Ear	ATF 2 Left Ear
0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0
-0.1	0.0	-0.1	-0.1
-0.1	-0.1	0.0	-0.1
0.0	-0.1	-0.1	-0.1
-0.1	-0.1	0.0	-0.1
Impulsive Peak Insertion Loss [*N = 32*]			
Mean IPIL		50.9 dB	
IPIL Standard Deviation		2.1 dB	

Table 16.
EB-15 flanged Tip 166 dB peak IPIL.

Free Field Pressure Data [*N = 14*]			
Mean Peak		165.7 dB	
Peak Standard Deviation		0.1 dB	
Mean A-duration		1.18 ms	
A-duration Standard Deviation		0.01 ms	
Difference between measured and estimated calibration shot peaks [dB]			
ATF 1 Right Ear	ATF 1 Left Ear	ATF 2 Right Ear	ATF 2 Left Ear
-0.2	0.0	0.0	-0.1
-0.1	0.0	-0.1	-0.2
-0.1	0.0	-0.1	-0.1
-0.2	-0.2	-0.1	-0.1
0.0	-0.1	0.0	0.0
-0.1	-0.1	-0.1	-0.1
Impulsive Peak Insertion Loss [*N = 32*]			
Mean IPIL		44.0 dB	
IPIL Standard Deviation		1.4 dB	

Table 17.
Surefire EP4® unvented 150 dB peak IPIL.

Free Field Pressure Data [*N* = *16*]			
Mean Peak		151.5 dB	
Peak Standard Deviation		0.4 dB	
Mean A-duration		0.85 ms	
A-duration Standard Deviation		0.01 ms	
Difference between measured and estimated calibration shot peaks [dB]			
ATF 1 Right Ear	ATF 1 Left Ear	ATF 2 Right Ear	ATF 2 Left Ear
-0.1	-0.1	0.0	0.0
0.1	0.0	-0.1	-0.1
0.1	0.0	0.1	0.1
0.1	0.1	0.0	0.0
-0.2	-0.1	0.0	0.0
0.0	0.0	0.0	0.0
Impulsive Peak Insertion Loss [*N* = *40*]			
Mean IPIL		35.2 dB	
IPIL Standard Deviation		2.2 dB	

Table 18.
Surefire EP4® vented 150 dB peak IPIL.

Free Field Pressure Data [*N* = *16*]			
Mean Peak		151.7 dB	
Peak Standard Deviation		0.3 dB	
Mean A-duration		0.85 ms	
A-duration Standard Deviation		0.01 ms	
Difference between measured and estimated calibration shot peaks [dB]			
ATF 1 Right Ear	ATF 1 Left Ear	ATF 2 Right Ear	ATF 2 Left Ear
-0.1	-0.2	0.0	0.0
0.1	-0.1	0.0	0.0
0.3	0.1	-0.1	-0.1
-0.1	0.1	0.0	0.0
-0.3	-0.1	0.0	0.0
0.0	0.1	0.1	0.0
Impulsive Peak Insertion Loss [*N* = *40*]			
Mean IPIL		27.7 dB	
IPIL Standard Deviation		0.9 dB	

Table 19.
Surefire EP4® unvented 166 dB peak IPIL.

Free Field Pressure Data [*N = 16*]			
Mean Peak		165.6 dB	
Peak Standard Deviation		0.2 dB	
Mean A-duration		1.18 ms	
A-duration Standard Deviation		0.00 ms	
Difference between measured and estimated calibration shot peaks [dB]			
ATF 1 Right Ear	ATF 1 Left Ear	ATF 2 Right Ear	ATF 2 Left Ear
-0.1	-0.3	-0.2	-0.2
0.0	-0.2	-0.1	-0.1
0.0	-0.1	-0.1	-0.1
-0.1	0.1	0.0	0.0
0.0	0.1	0.1	0.0
-0.2	0.0	0.2	0.1
Impulsive Peak Insertion Loss [*N = 40*]			
Mean IPIL		31.9 dB	
IPIL Standard Deviation		4.9 dB	

Table 20.
Surefire EP4® vented 166 dB peak IPIL.

Free Field Pressure Data [*N = 16*]			
Mean Peak		165.8 dB	
Peak Standard Deviation		0.2 dB	
Mean A-duration		1.18 ms	
A-duration Standard Deviation		0.00	
Difference between measured and estimated calibration shot peaks [dB]			
ATF 1 Right Ear	ATF 1 Left Ear	ATF 2 Right Ear	ATF 2 Left Ear
0.1	0.2	0.3	0.2
0.0	0.1	0.2	0.1
0.0	0.1	0.2	0.1
-0.2	-0.3	-0.3	-0.3
0.0	-0.2	-0.3	-0.2
-0.1	-0.2	-0.3	-0.3
Impulsive Peak Insertion Loss [*N = 40*]			
Mean IPIL		29.9 dB	
IPIL Standard Deviation		2.0 dB	

Discussion

Continuous noise attenuation

Among the vented earplugs, the Combat Arms Plug provided the lowest amount of attenuation at all frequencies (on average), while the Surefire EP4® and BattlePlug® showed similar attenuation levels, with the EP4® providing more attenuation on average at most frequencies. The standard deviations of the attenuation values were between 3 and 8 dB for the vented plugs.

The solid plugs, ranked from least attenuation to most attenuation (in general), were the EB-15 with the flanged tip, the Combat Arms Earplug™, the BattlePlug®, the Surefire EP4®, and the EB-15 with the foam tip. The standard deviations of the attenuation values were 3 to 12 dB for all of the plugs. The standard deviations for the EB-15 with the flanged tip were greater than 10 dB for all frequencies.

In both the vented and unvented configurations, the Surefire EP4® showed a notch in the attenuation at 4 kHz. Comparison of the vented and solid plugs shows that the vented plugs demonstrate much less attenuation at low frequencies.

Localization testing

The localization test results show on average an increase in mean error and a decrease in percentage of correct responses between the open ear tests and tests where participants were wearing HPDs (in other words, localization performance was worse when wearing earplugs). This result was expected. In the case of the EP4® plugs, the average mean error was slightly lower with the plugs closed than in the open ear trials, though the percent of correct responses was better in the open ear condition.

When comparing the vented to unvented results for the same device, the BattlePlug® and the EP4® plugs showed an average decrease in mean error and an increase in correct responses when the vents were closed (localization performance was better with the vents closed). The Combat Arms Earplug™ showed a decrease in correct responses and an increase in mean error when using the unvented plugs (localization performance was better with the vented plug).

Localization performance with the EB-15 plugs was slightly better with the foam ear tips than with the flanged ear tips in terms of percent correct, but reversed in terms of mean error.

The vented plugs ranked from best to worst localization performance are the Combat Arms Plug, the BattlePlug®, and the Surefire EP4®. Ranking the solid plugs is more complicated. In terms of percent correct responses, the best to worst ranking is the Combat Arms Earplug™, tie between the EB-15 flanged tip and the Surefire EP4®, the EB-15 foam tip, and BattlePlug®. In terms of mean error, however, the ranking would be BattlePlug®, EB-15 flanged tip, EB-15 foam tip, Surefire EP4®, and the Combat Arms Earplug™.

The open ear results for the localization tests indicated very poor performance in localization among the test participants in this study. The average percent of correct responses for the open ear tests for all four devices was around 50 percent. Test number 6 for the BattlePlug® and test

number 4 for the Combat Arms Earplug™ showed near perfect open ear responses, and severe decrements in localization performance when wearing the HPDs, both vented and unvented. The majority of the other test results show very low rates of correct responses in the open ear measures, and less severe decrements in localization performance when wearing the HPDs (and in some cases improvements in localization performance). There are two reasonable explanations for these results.

It is possible that the test methodology (including the cumbersome response method, the variable time between stimuli, the dark test environment, etc.) resulted in systematic errors in the test. Similar test methods have been used at other laboratories for localization testing (Gilkey et al, 1995), but the authors cannot eliminate the possibility of errors in the test method. It is also possible that the participants in this study were mostly poor localizers. No effort was made to screen participants based on localization ability. Furthermore, the participants were given no opportunity to practice the test prior to data collection.

The issue of poor open ear scores is relevant to interpreting the test results and defining acceptable limits for HPD selection (which is outside the range of this test). If a volunteer had 100% accuracy with no HPD, and 50% accuracy with an HPD, the test would indicate a significant decrease in accuracy when wearing the HPD. If, however, a volunteer had 55% accuracy with no HPD, and 50% accuracy with the HPD, the test would indicate that localization performance was not much worse with the HPD.

Interpreting the results of this test for generalized conclusions about localization test methodology is outside the scope of this test. Prior to collecting data, the authors believed that the test results would be more straightforward, and would allow the devices to simply be ranked in terms of best to worst performance. Instead, the results have caused the test methodology to be questioned. Localization test methodology at USAARL is currently being updated and improved. Overall, the authors have little confidence in the results of this test.

Impulsive noise insertion loss

The transfer functions between the free field probe and the ears of the ATFs used in testing provided good estimates of the unprotected signals. Evidence of this is the near perfect agreement between the estimated un-protected shots and the measured un-protected shots for the six calibration shots from each series of testing.

The BattlePlug® and the Combat Arms Earplug™ showed approximately the same insertion loss at 150 and 166 dB in the unvented configuration. The EP4® showed less insertion loss than the other two passive earplugs in the unvented configuration, and showed a decrease in insertion loss as the level increased from 150 to 166 dB. Typically, HPDs increase in insertion loss as the peak free field level increases.

In the vented configuration, the BattlePlug® and Combat Arms Earplug™ again showed similar insertion loss, with the BattlePlug® having slightly more insertion loss than the Combat Arms Earplug™ at 150 dB peak. The EP4® showed less insertion loss than the other two earplugs in the vented configuration.

The EB-15 acting as a passive earplug showed significantly more insertion loss with both the flanged and foam ear tip than the other three devices. The foam ear tip showed significantly more insertion loss than the flanged ear tip.

Vented earplugs are often described as providing protection from impulsive noise. The general trend of increasing IPIL with increasing peak sound pressure level is often used to describe the plugs as providing more protection as impulse level increases. The authors are not aware of any specific studies that correlate higher IPIL with more protection, nor are they aware of any studies that correlate IPIL to protective capacity in general. At least one very limited temporary threshold shift study has been conducted to test the effectiveness of a vented plug. In that study, volunteers using vented plugs had lower threshold shifts than volunteers with no hearing protection, indicating that vented plugs offer some protection (Mosko and Fletcher, 1971). It seems logical to assume that a plug with a higher IPIL would provide more protection, but this relationship is not proven.

Other observations

While comfort and usability were not aspects covered in this study, it is worth mentioning that several test participants commented favorably on the comfort of the EP4® earplugs as compared to the other plugs tested. Examination of the EP4® plugs reveals that the flanged portion that enters into the ear canal is more flexible than the other plugs, possibly leading to increased comfort due to the plug deforming rather than pressing against the inside of the ear canal. Additionally, the unique retention system of the EP4® may aid users in consistently fitting the device. Correctly fitting the retention system may lead to users inserting the plug to a consistent depth, while giving confidence that the plug will not be inserted too deeply and require assistance in extracting. Several participants were active or reserve military personnel, and they commented that the fit of the EP4® (i.e. conforming to the inside of the pinnae and not extending out of the pinnae) could be useful in allowing individuals to don headsets for communication without removing the earplugs (obviously, wearing the plugs under a communication headset would degrade the speech intelligibility of the headset).

The softer material used to construct the EP4® seems to be more fragile, and can be more easily torn by rough handling (degrading the performance of the protector). During the impulse noise testing, 4 samples of the EP4® were damaged by inserting or extracting the plug from the ATF. Additionally, one participant who was familiar with the EP4® commented on how easy the plugs were to tear. The EP4® is also available in multiple sizes, but the ear tips and retention system are sized and packaged together. Some individuals felt that their ear canals could accept a larger ear tip, but the larger retention system would not fit in their pinnae (or vice versa). Although this option can lead to damaging the plug, the retention system may be removed from the ear tip and exchanged for one of a different size.

Conclusions and recommendations

Four passive hearing protection devices were evaluated for continuous noise attenuation, auditory localization, and impulse noise insertion loss. The vented EP4® and BattlePlug®

provided more continuous attenuation than the vented Combat Arms Earplug™. The foam tipped EB-15 plug provided the most continuous noise attenuation. The localization test results did not produce a clear best product, but rather suggested that the localization test method was flawed. The EB-15 showed the highest IPIL results, regardless of ear tip used. Among the vented plugs, the Combat Arms Earplug™ and BattlePlug® demonstrated the highest IPIL ratings.

Subjective localization testing is generally time consuming and can be expensive. It is recommended that an ATF test method be developed to predict the effects of HPDs on localization ability. It is also recommended that a systematic evaluation of the actual protective capacity of passive and active non-linear HPDs be undertaken to determine the actual required specifications needed to protect the hearing of individuals in the armed forces.

References

American National Standards Institute. 2008. Methods for the measurement of the real-ear attenuation of hearing protectors. Melville, NY. ANSI S12.6-2008

American National Standards Institute. 2010. Methods for the measurement of insertion loss of hearing protection devices in continuous or impulsive noise using microphone-in-real-ear or acoustic test fixture procedures. Melville, NY. ANSI S12.42-2010

Etymotic Research Inc. EB-15 BlastPLG. Undated. Accessed on 8 April 2014 from http://www.etymotic.com/hp/eb15le.html

Gilkey, R. H., Good, M. D., Ericson, M. A., Brinkman, J., and Steward, J. M. 1995. A pointing technique for rapidly collecting localization responses in auditory research. Behavior Research Methods, Instruments, & Computers. 27(1), 1-11.

Moldex. BattlePlugs Impulse Earplugs. Undated. Accessed on 8 April 2014 from http://www.moldex.com/government-division/hearing-protection/reusable-earplugs/battleplugs.php

Mosko, J. D. and Fletcher, J. L. 1971. Evaulation of the Gundefender Earplug: Temporary Threshold Shift and Speech Intelligibility. The Journal of the Acoustical Society of America. Technical Notes and Research Briefs. Vol. 49. Number 6. Part 1.

Murphy, W. J., Flamme, G. A., Meinke, D. K., Sondergaard, J., Finan, D. S., Lankford, J. E., Khan, A., Vernon, J., Stewart, M. 2011. Measurement of impulse peak insertion loss for four hearing protection devices in field conditions. International Journal of Audiology. 00: 1-12.

Surefire. EP4 Sonic Defenders Plus. Undated. Accessed on 8 April 2014 from http://www.surefire.com/ep4-sonic-defenders-plus.html

U.S. Department of Veteran's Affairs, Veterans Benefit Administration. 2012. Annual Benefits Report, FY2012.

3M. Combat Arms Earplug. Undated. Accessed on 8 April 2014 from http://solutions.3m.com/

Appendix A.

Individual REAT test results.

Shown below are the attenuation values from each of the 20 REAT tests for each of the devices.

Table 21.
Attenuation – Combat Arms Earplug™ – vented.
All attenuation values in decibels.

Test #	125 Hz	250 Hz	500 Hz	1k Hz	2k Hz	4k Hz	8k Hz
1.0	2.1	4.5	5.6	8.8	12.6	23.8	16.8
2.0	11.0	11.1	10.6	14.1	36.2	21.5	19.2
3.0	1.1	-2.5	-2.3	0.5	1.0	4.8	2.5
4.0	8.0	5.4	11.9	14.2	22.4	15.5	18.0
5.0	4.3	3.6	3.9	12.2	20.2	15.4	14.0
6.0	0.3	3.8	9.1	19.1	24.0	20.4	16.9
7.0	4.6	8.3	11.5	16.3	28.8	19.0	22.3
8.0	8.9	4.6	2.5	6.9	12.2	11.0	14.8
9.0	5.0	3.5	4.5	6.0	22.0	17.0	21.5
10.0	1.5	2.0	3.0	15.0	26.5	22.5	14.0
11.0	4.5	3.5	6.5	13.5	18.5	17.5	17.0
12.0	3.8	5.9	11.6	18.5	23.3	24.0	20.6
13.0	-1.9	-0.1	7.2	15.5	22.1	24.4	13.4
14.0	3.5	7.0	11.5	21.0	30.0	22.5	21.0
15.0	0.0	2.0	7.0	14.5	31.5	20.0	17.5
16.0	7.0	3.5	10.0	11.0	22.0	22.5	28.5
17.0	0.5	1.5	7.5	12.5	24.0	16.0	15.5
18.0	4.4	10.0	12.4	14.6	29.7	20.8	15.7
19.0	8.5	13.0	13.5	17.5	25.0	25.5	21.0
20.0	4.0	6.5	6.5	13.0	15.5	17.5	22.5
Mean	4.0	4.8	7.7	13.2	22.4	19.1	17.6
Standard Deviation	3.4	3.7	4.1	4.8	7.9	5.0	5.2

Table 22.
Attenuation – Combat Arms Earplug™ – unvented.
All attenuation values in decibels.

Test #	125 Hz	250 Hz	500 Hz	1k Hz	2k Hz	4k Hz	8k Hz
1	11.7	9.9	7.4	12.0	18.0	18.5	32.4
2	27.6	23.2	33.1	25.0	46.5	38.5	42.2
3	1.0	-1.7	-3.4	0.3	1.7	6.0	2.0
4	18.8	16.3	15.0	17.8	23.8	18.2	29.6
5	8.5	3.0	4.9	11.9	19.7	16.4	19.0
6	24.9	25.9	28.6	30.8	32.8	30.3	35.2
7	23.7	24.3	26.1	26.8	37.2	34.0	42.5
8	20.2	16.6	12.3	7.9	15.4	15.5	34.2
9	25.0	17.0	15.0	13.5	25.0	29.0	35.5
10	26.5	27.0	20.0	19.5	29.5	29.0	33.0
11	2.0	1.5	5.5	12.0	16.0	15.5	14.5
12	27.4	29.6	31.6	32.3	35.4	37.7	48.5
13	27.6	28.2	31.7	24.6	27.5	31.2	41.8
14	17.0	17.0	21.0	28.5	36.5	30.5	44.0
15	24.0	28.0	24.5	23.5	37.5	33.0	39.0
16	25.5	21.5	21.5	15.5	23.5	26.0	32.0
17	23.5	23.0	23.0	21.5	33.5	26.5	41.0
18	27.9	29.5	27.3	23.4	30.1	23.5	40.6
19	24.0	26.5	24.0	20.5	27.0	25.5	38.5
20	28.0	28.0	26.0	24.0	31.0	39.0	40.0
Mean	20.7	19.7	19.7	19.5	27.4	26.2	34.3
Standard Deviation	8.5	9.7	10.1	8.2	10.0	8.9	11.1

Table 23.
Attenuation – BattlePlug® – vented.
All attenuation values in decibels.

Test #	125 Hz	250 Hz	500 Hz	1k Hz	2k Hz	4k Hz	8k Hz
1	7.0	11.5	20.0	24.5	32.0	30.5	25.5
2	4.9	6.9	6.0	15.3	31.4	18.8	21.5
3	10.8	11.0	12.4	12.8	24.4	30.0	24.6
4	6.6	6.9	11.6	13.4	25.5	29.6	24.1
5	1.6	1.4	5.1	12.4	19.3	18.4	14.8
6	11.4	12.5	20.4	27.3	29.8	30.4	24.4
7	4.2	7.1	8.4	8.6	26.6	18.9	22.4
8	12.9	4.7	9.6	15.1	23.9	25.3	24.8
9	8.5	8.0	10.0	10.0	25.5	20.5	21.0
10	11.0	4.5	7.5	17.5	27.5	22.5	29.0
11	1.5	1.5	1.0	10.0	13.5	21.0	8.5
12	2.2	0.7	16.5	19.6	33.8	36.9	32.1
13	-0.2	1.9	3.6	13.2	19.2	23.5	15.9
14	3.0	8.0	13.0	17.0	32.5	27.0	25.0
15	6.0	6.0	14.5	16.5	24.5	25.0	29.0
16	7.0	9.5	13.0	15.5	29.5	17.5	21.0
17	7.9	9.8	11.3	19.5	30.5	37.1	27.4
18	3.0	10.0	10.5	15.0	29.5	35.5	27.0
19	11.5	20.0	20.5	21.5	30.5	38.0	30.5
20	4.5	10.0	11.0	17.5	25.0	33.5	26.0
Mean	6.3	7.6	11.3	16.1	26.7	27.0	23.7
Standard Deviation	3.9	4.6	5.4	4.8	5.1	6.8	5.6

Table 24.
Attenuation – BattlePlug® – unvented
All attenuation values in decibels.

Test #	125 Hz	250 Hz	500 Hz	1k Hz	2k Hz	4k Hz	8k Hz
1	25.0	30.0	33.0	29.0	37.5	35.5	24.5
2	15.2	15.1	15.4	25.3	38.3	30.2	21.2
3	20.5	20.4	15.9	14.1	26.2	31.1	26.4
4	20.9	21.6	23.0	16.3	27.0	29.5	26.1
5	21.3	19.7	24.6	22.3	26.2	29.4	23.1
6	27.4	26.5	31.3	29.5	32.6	29.7	25.2
7	20.6	24.2	21.8	19.8	32.7	28.5	24.9
8	29.8	28.3	24.8	19.0	27.4	26.5	26.1
9	22.5	18.0	13.5	11.0	28.0	28.5	29.5
10	27.0	18.0	15.5	17.5	29.0	24.5	26.0
11	1.0	0.5	1.0	11.0	12.5	18.5	8.0
12	26.6	22.5	32.0	24.3	36.6	30.8	31.8
13	24.8	24.3	28.4	23.8	26.8	30.5	26.9
14	28.5	29.5	32.0	23.0	36.5	22.5	25.5
15	28.5	29.0	32.5	23.0	33.0	25.0	35.5
16	20.5	21.5	18.0	21.0	31.5	16.0	21.0
17	27.8	23.9	20.0	19.1	32.2	34.7	25.2
18	19.5	23.5	19.5	18.0	32.0	28.0	26.5
19	30.0	34.0	27.5	25.5	34.5	45.5	32.0
20	24.0	26.5	24.0	24.5	27.0	31.5	29.5
Mean	23.1	22.8	22.7	20.8	30.4	28.8	25.7
Standard Deviation	6.6	7.1	8.1	5.2	5.8	6.2	5.5

Table 25.
Attenuation – Surefire EP4® – vented.
All attenuation values in decibels.

Test #	125 Hz	250 Hz	500 Hz	1k Hz	2k Hz	4k Hz	8k Hz
1	8.5	7.0	12.6	18.4	23.9	15.5	22.1
2	8.0	7.9	15.7	20.0	20.7	17.2	34.2
3	5.0	8.7	15.6	23.2	31.8	20.7	25.3
4	7.5	13.7	18.7	20.1	30.0	18.8	35.7
5	16.0	10.5	11.0	11.5	22.0	12.5	35.0
6	7.0	-0.5	8.0	20.0	29.5	22.5	22.5
7	5.5	5.0	10.5	16.5	24.0	13.0	26.0
8	4.5	7.5	12.0	13.5	27.0	24.0	30.5
9	4.6	4.8	15.0	11.5	29.9	26.8	28.0
10	6.0	8.0	15.0	20.0	28.5	15.0	38.5
11	6.0	8.0	17.0	17.5	28.5	21.0	30.5
12	10.0	11.5	17.5	19.5	28.5	29.0	39.0
13	5.0	5.5	12.0	14.5	25.0	14.5	31.0
14	8.6	11.0	15.9	23.9	35.5	27.7	21.5
15	6.0	12.5	13.0	17.5	30.5	21.5	41.5
16	8.5	13.0	15.5	19.5	28.5	23.0	35.5
17	11.0	11.5	15.5	14.5	25.0	14.0	40.0
18	11.5	16.0	18.5	22.0	27.0	33.0	44.0
19	3.0	6.5	12.5	12.5	22.0	27.0	24.5
20	8.0	6.0	3.0	20.0	19.5	21.0	44.5
Mean	7.5	8.7	13.7	17.8	26.9	20.9	32.5
Standard Deviation	3.0	3.8	3.8	3.7	4.1	5.8	7.4

Table 26.
Attenuation – Surefire EP4® – unvented.
All attenuation values in decibels.

Test #	125 Hz	250 Hz	500 Hz	1k Hz	2k Hz	4k Hz	8k Hz
1	18.0	17.3	19.8	17.5	24.1	20.9	30.3
2	25.8	21.4	25.7	24.5	25.6	17.7	32.8
3	36.5	36.7	39.1	36.5	36.7	19.5	20.0
4	22.2	23.7	25.5	22.1	32.0	17.9	39.0
5	17.0	12.0	10.0	10.0	24.0	18.0	32.0
6	33.5	24.5	25.5	24.0	35.0	29.0	28.0
7	29.5	27.5	32.5	22.0	28.0	34.5	45.0
8	26.5	24.0	27.0	23.0	28.5	29.5	26.5
9	29.4	22.6	24.4	28.3	32.1	27.8	27.1
10	30.5	29.0	30.5	33.5	36.5	20.0	43.0
11	25.5	22.5	27.5	26.0	32.0	15.0	36.0
12	29.5	29.0	28.0	24.5	33.5	23.5	40.5
13	22.0	20.5	18.5	20.5	31.0	14.0	29.0
14	31.5	29.4	25.8	24.9	41.8	25.6	23.8
15	22.0	25.0	21.0	25.0	38.5	25.5	44.5
16	22.0	22.5	20.5	19.0	30.5	19.0	35.0
17	30.5	19.5	19.5	17.5	23.0	17.0	40.0
18	34.5	33.0	32.0	29.5	36.0	33.0	41.0
19	24.0	26.5	26.5	21.0	27.0	26.0	27.5
20	21.5	20.0	18.0	20.0	29.0	27.0	31.5
Mean	26.6	24.3	24.9	23.5	31.2	23.0	33.6
Standard Deviation	5.5	5.6	6.4	5.8	5.2	6.0	7.3

Table 27.
Attenuation – EB-15 – passive, flanged ear tip.
All attenuation values in decibels.

Test #	125 Hz	250 Hz	500 Hz	1k Hz	2k Hz	4k Hz	8k Hz
1	15.8	13.5	17.6	27.3	27.7	19.9	24.0
2	18.7	19.0	20.8	18.9	22.8	23.6	31.0
3	16.7	16.4	13.7	17.8	36.9	21.4	20.7
4	-0.3	3.1	-0.8	-3.8	-2.5	3.2	3.5
5	19.2	16.7	14.5	15.3	22.9	15.1	27.1
6	0.1	1.3	3.7	7.8	15.2	11.9	11.0
7	41.4	39.7	44.4	43.0	39.5	41.0	33.6
8	20.4	21.4	23.4	28.0	31.8	23.2	40.6
9	35.5	37.0	44.0	32.0	37.0	37.5	45.0
10	15.5	17.0	18.5	14.5	23.0	14.5	26.0
11	6.5	2.0	1.0	4.5	19.0	13.0	18.0
12	25.0	27.5	23.5	22.5	32.5	32.0	24.0
13	3.0	3.0	4.0	9.0	10.5	15.0	6.5
14	30.5	20.3	30.1	30.9	33.5	36.8	37.3
15	1.7	-1.2	0.6	18.2	20.9	22.2	37.6
16	31.0	31.0	35.5	35.0	34.0	34.0	44.5
17	3.0	2.0	3.5	2.5	15.5	14.5	10.5
18	14.0	14.5	16.0	19.0	28.0	25.0	33.5
19	30.5	30.0	33.0	25.5	32.5	34.5	39.5
20	13.5	13.0	11.5	14.5	20.0	17.5	24.5
Mean	17.1	16.3	17.9	19.1	25.0	22.8	26.9
Standard Deviation	12.4	12.3	14.0	11.8	10.4	10.2	12.4

Table 28.
Attenuation – EB-15 – passive, foam ear tip.
All attenuation values in decibels.

Test #	125 Hz	250 Hz	500 Hz	1k Hz	2k Hz	4k Hz	8k Hz
1	22.4	22.0	18.7	21.0	31.6	34.2	36.9
2	26.5	29.0	33.8	32.2	32.3	44.0	37.4
3	25.9	17.0	16.7	18.9	42.4	40.2	47.8
4	22.0	19.7	16.4	17.5	26.2	31.0	39.5
5	21.0	15.2	14.9	19.4	32.2	35.4	39.3
6	22.7	24.0	27.2	24.5	32.0	37.4	38.7
7	37.3	34.0	33.2	30.2	35.4	41.8	34.5
8	37.4	38.4	38.8	37.4	36.0	41.8	48.4
9	32.5	35.5	40.0	32.5	35.0	34.5	46.0
10	25.5	22.3	25.1	17.7	31.1	33.8	38.8
11	34.0	24.5	27.5	26.5	32.5	35.0	46.0
12	29.5	30.0	23.5	23.0	36.0	41.5	44.5
13	32.0	29.0	30.5	26.5	34.0	42.0	43.0
14	33.2	33.8	30.5	35.1	32.3	39.1	46.9
15	26.8	25.3	32.3	27.4	27.4	36.9	36.8
16	33.0	31.0	32.5	41.0	38.0	40.0	49.5
17	18.5	16.5	14.5	21.5	34.5	35.5	42.5
18	22.0	19.5	18.5	20.5	33.5	28.5	44.5
19	25.5	21.0	24.0	25.0	35.5	36.5	36.5
20	19.5	20.5	18.0	21.5	28.0	32.5	32.0
Mean	27.4	25.4	25.8	26.0	33.3	37.1	41.5
Standard Deviation	5.9	6.8	8.0	6.8	3.7	4.1	5.1

<u>Appendix B.</u>

<u>Individual localization test results.</u>

Shown below are the individual responses to the localization test for each of the 40 localization tests completed (10 tests per device).

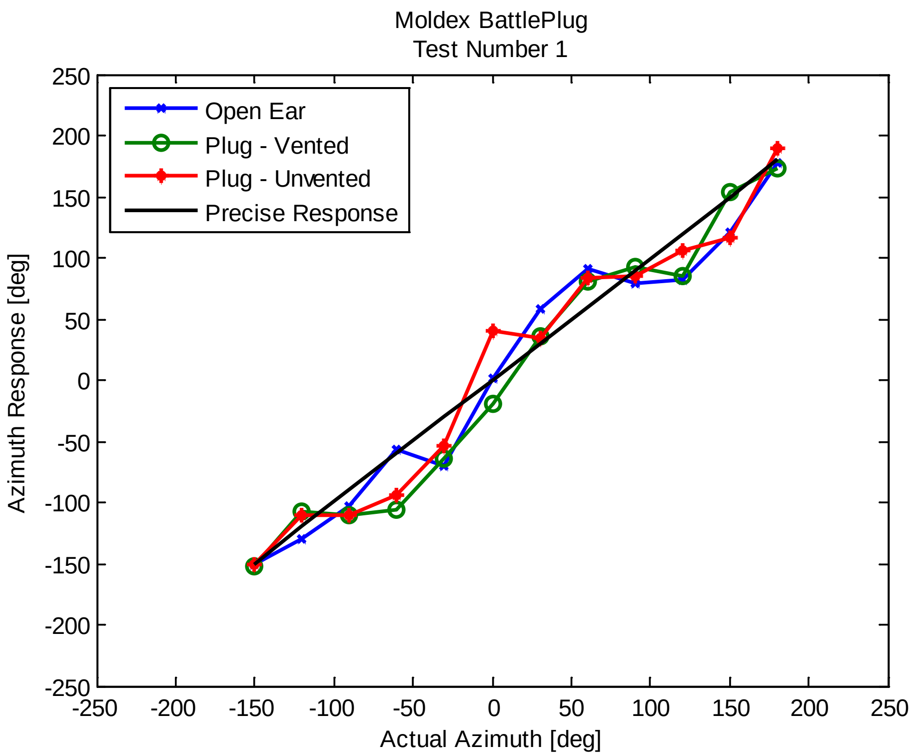

Figure B-1. BattlePlug® localization test 1 results.

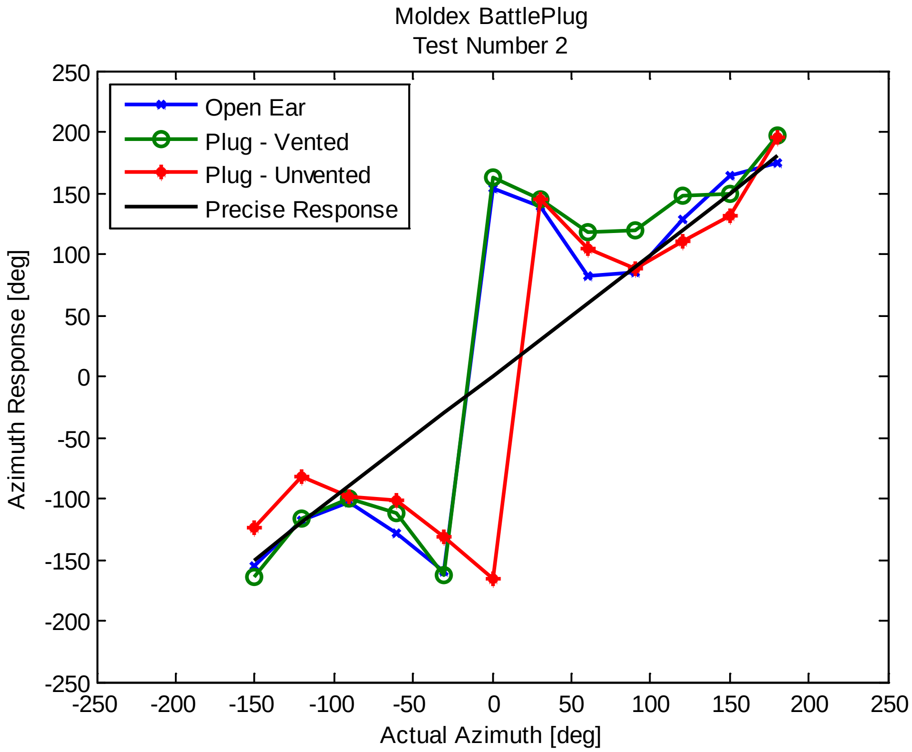

Figure B-2. BattlePlug® localization test 2 results.

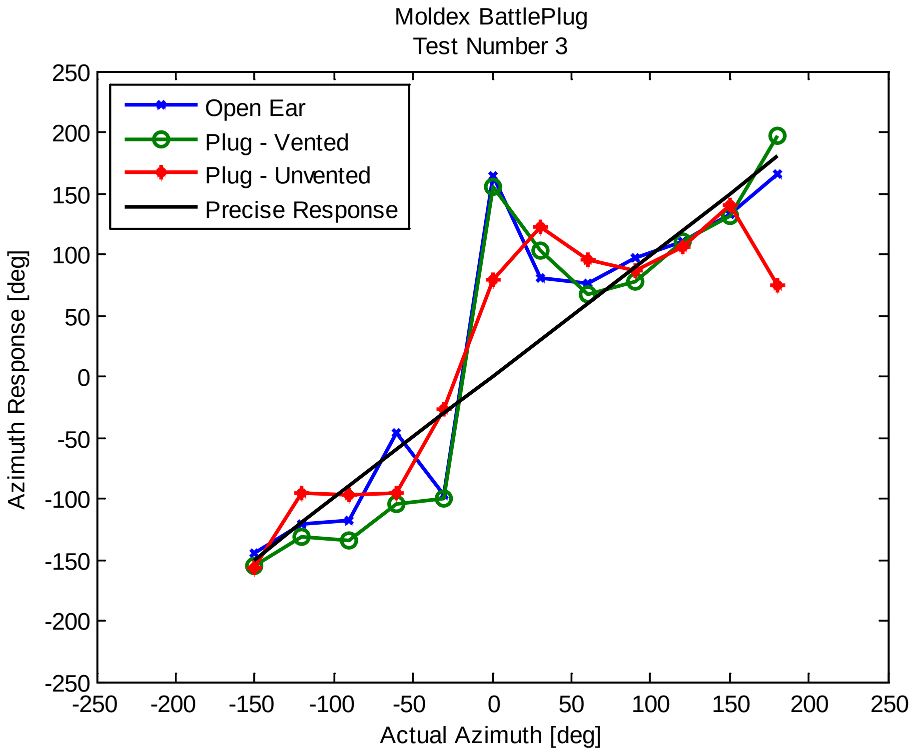

Figure B-3. BattlePlug® localization test 3 results.

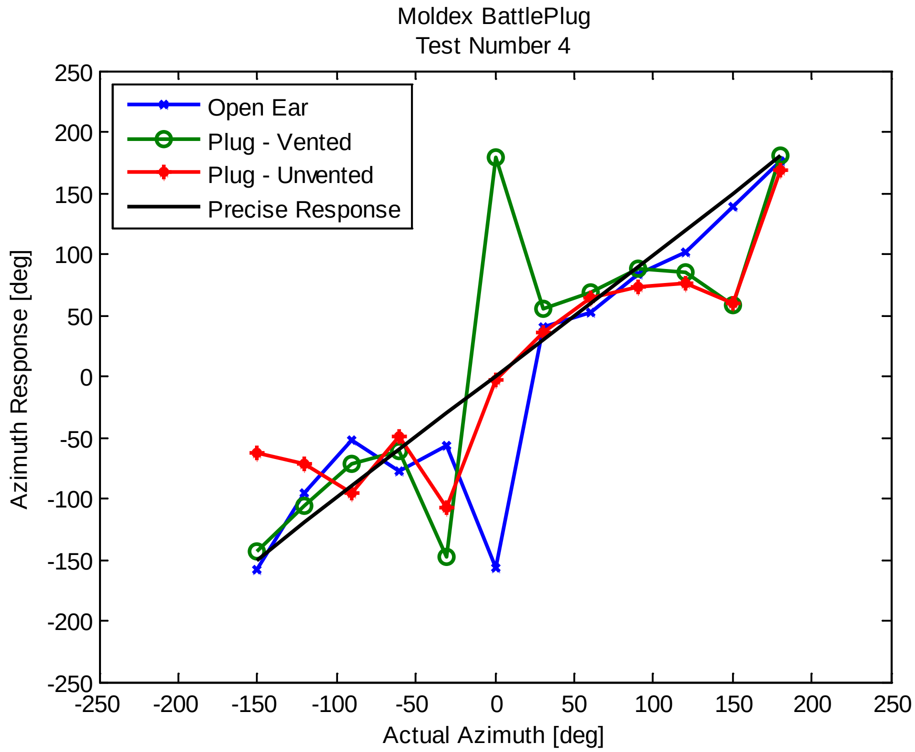

Figure B-4. BattlePlug® localization test 4 results.

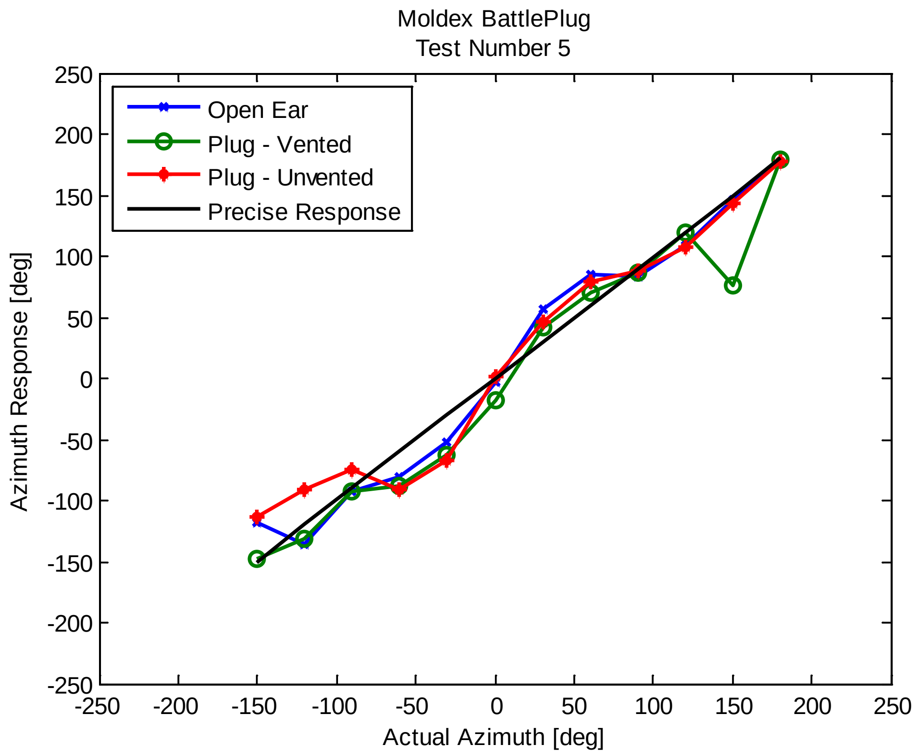

Figure B-5. BattlePlug® localization test 5 results.

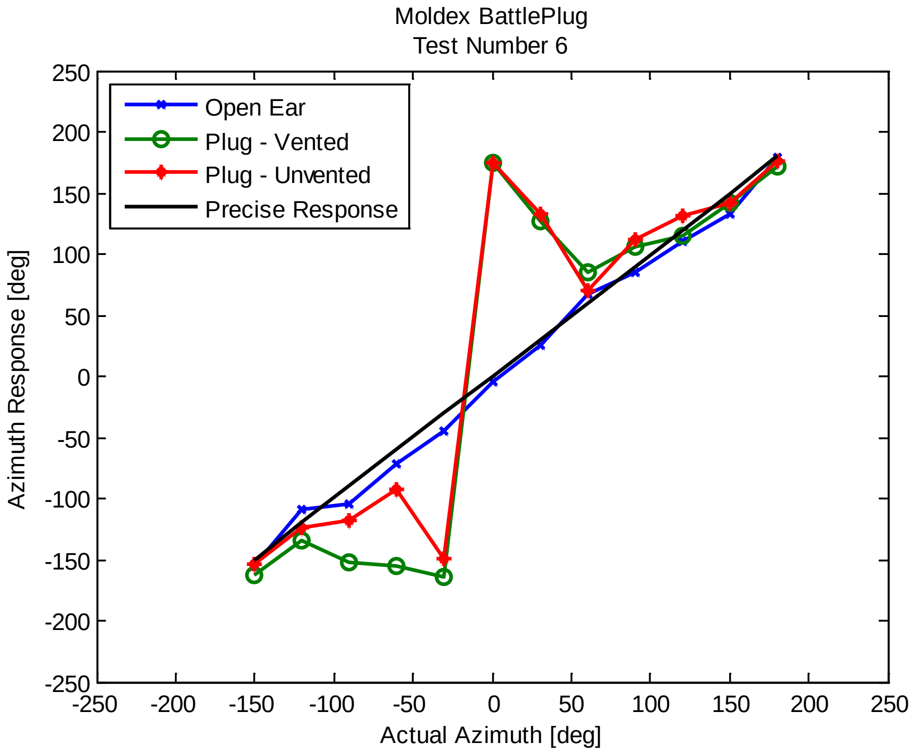

Figure B-6. BattlePlug® localization test 6 results.

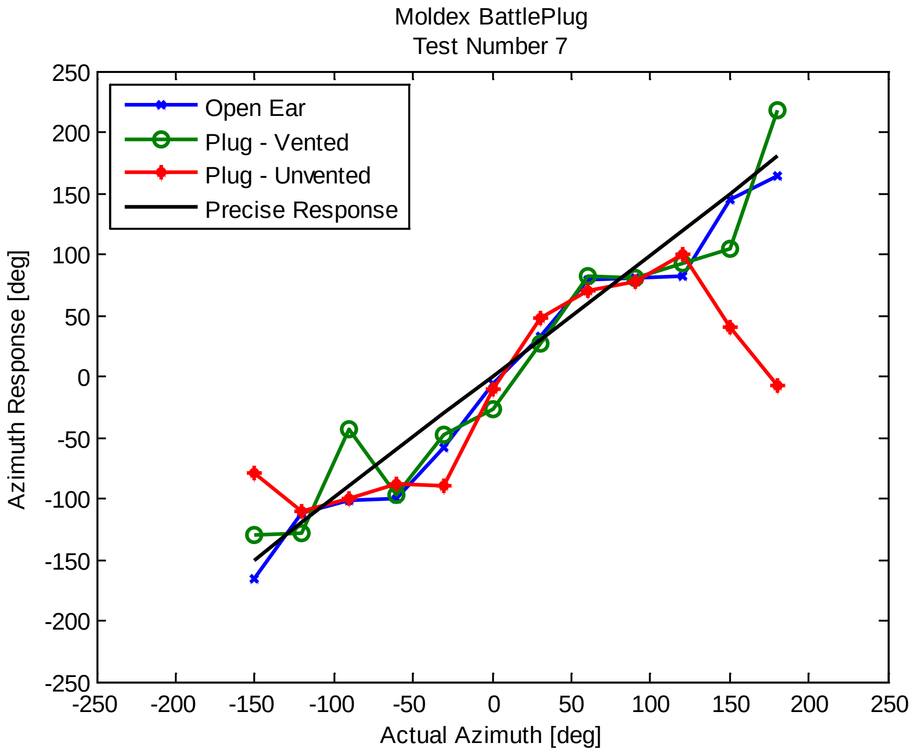

Figure B-7. BattlePlug® localization test 7 results.

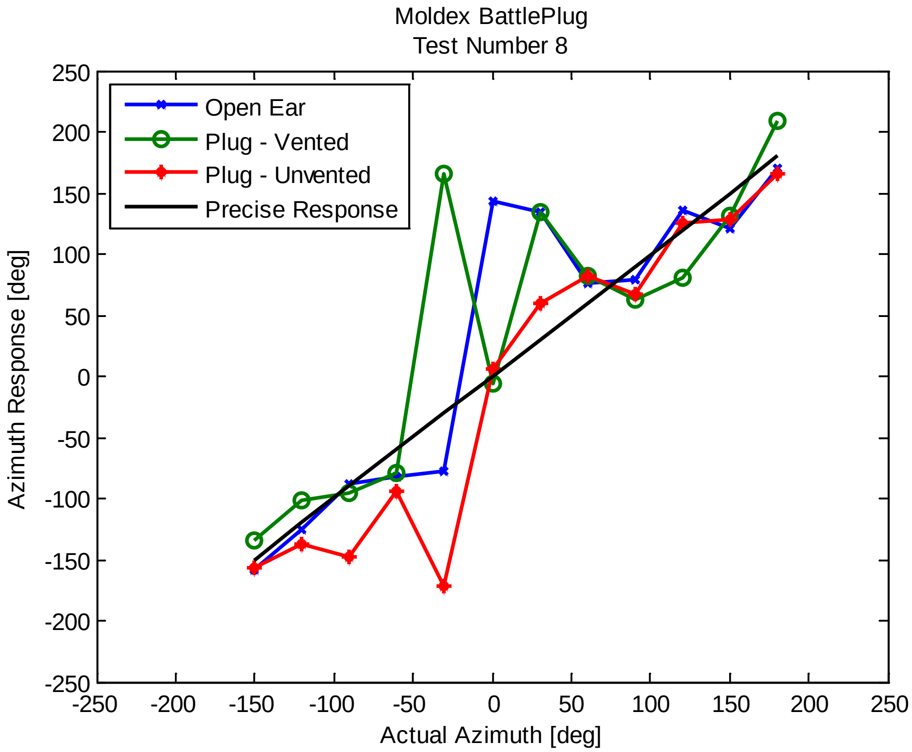

Figure B-8. BattlePlug® localization test 8 results.

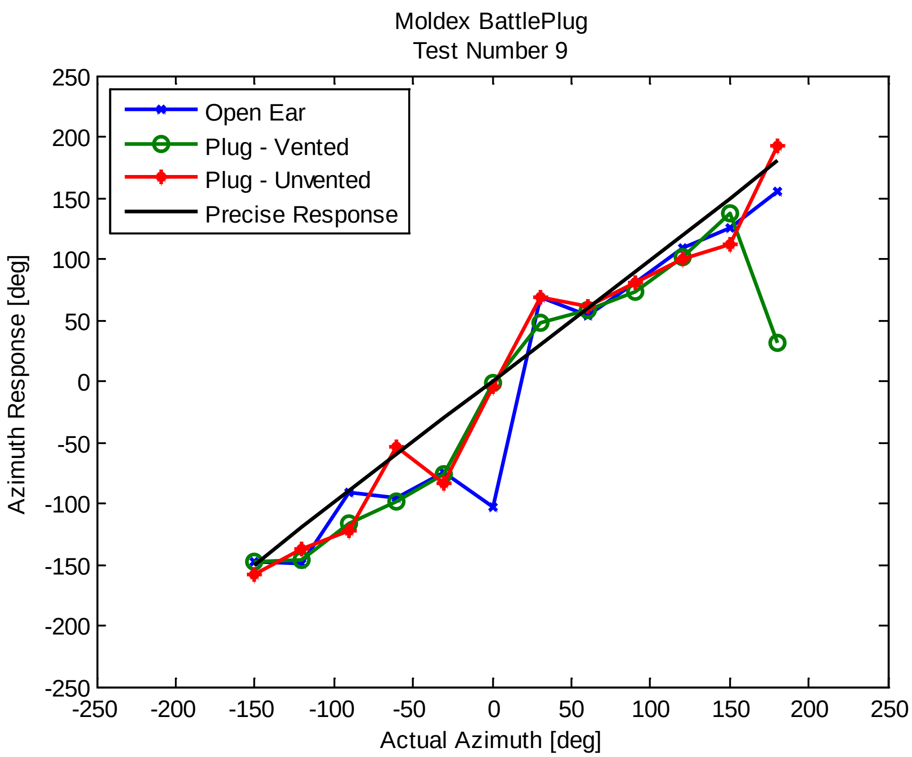

Figure B-9. BattlePlug® localization test 9 results.

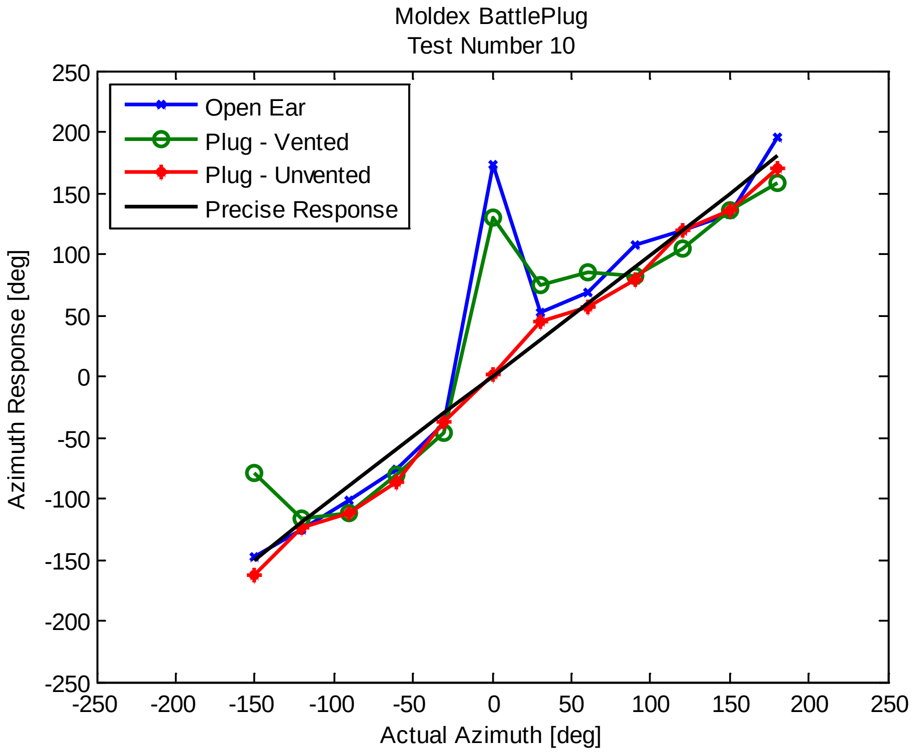

Figure B-10. BattlePlug® localization test 10 results.

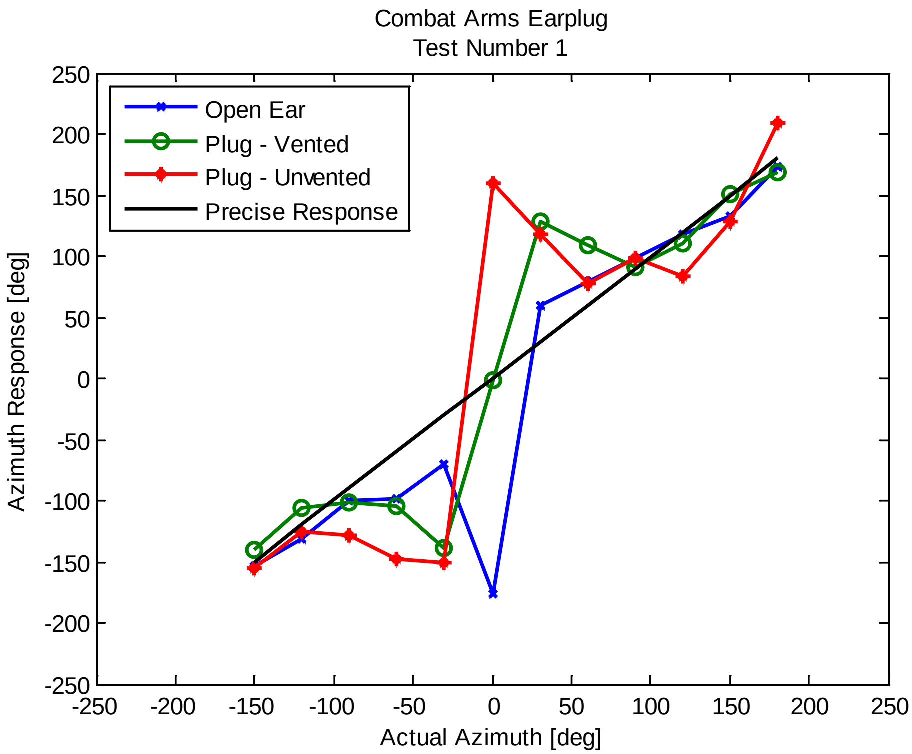

Figure B-11. Combat Arms Earplug™ localization test 1 results.

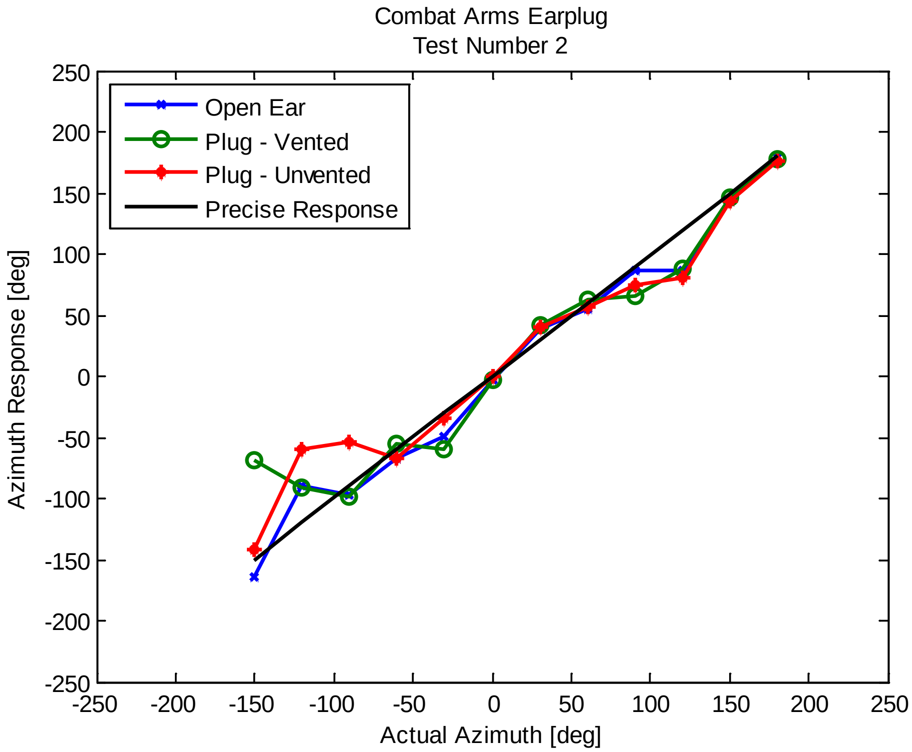

Figure B-12. Combat Arms Earplug™ localization test 2 results.

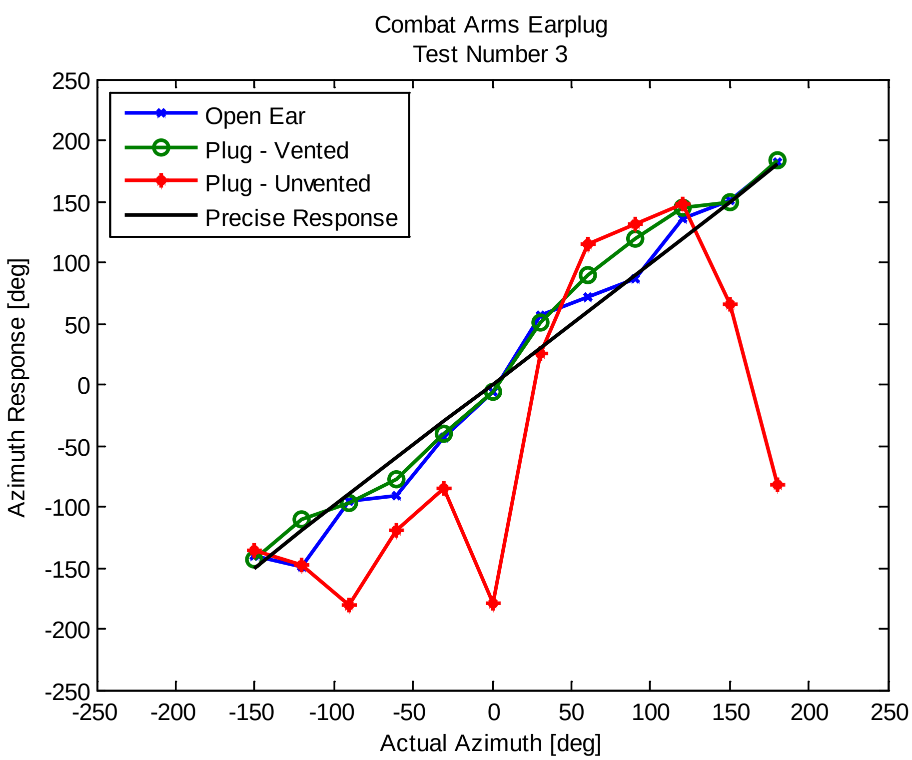

Figure B-13. Combat Arms Earplug™ localization test 3 results.

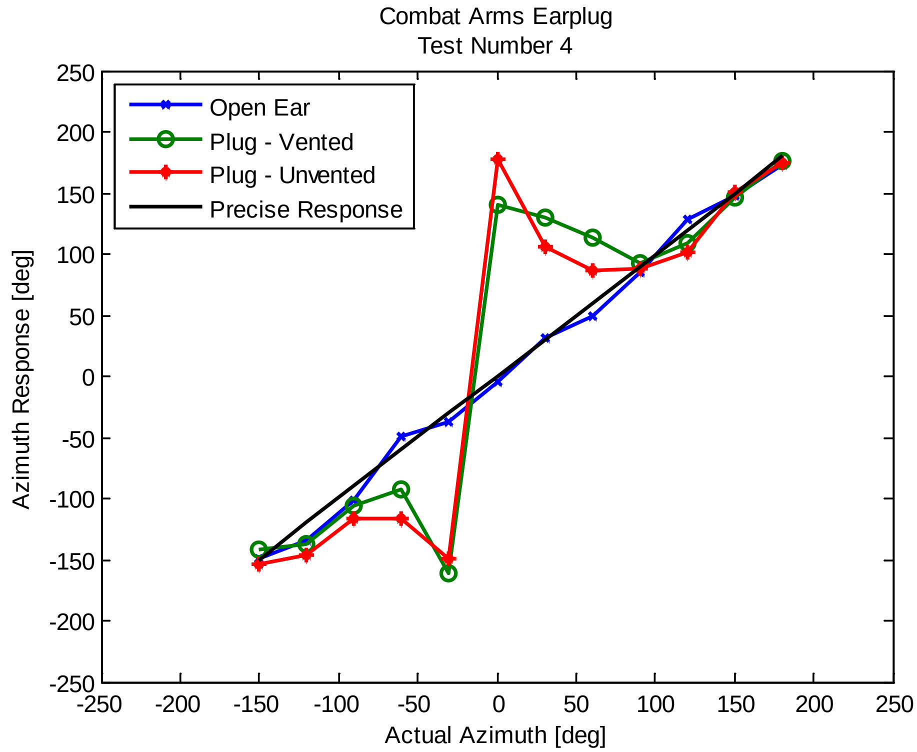

Figure B-14. Combat Arms Earplug™ localization test 4 results.

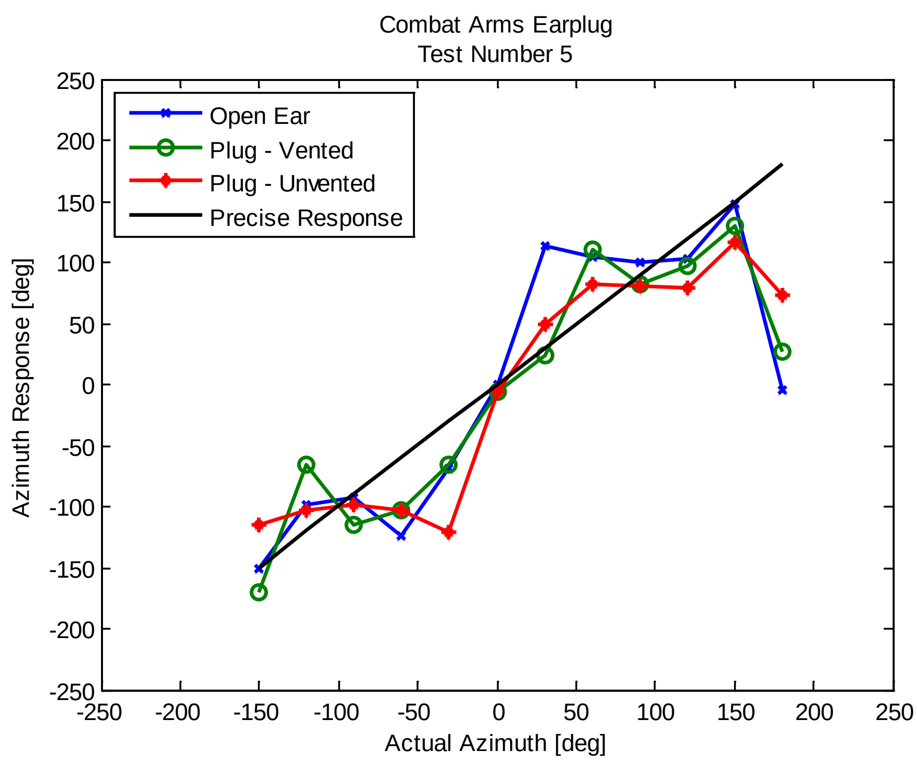

Figure B-15. Combat Arms Earplug™ localization test 5 results.

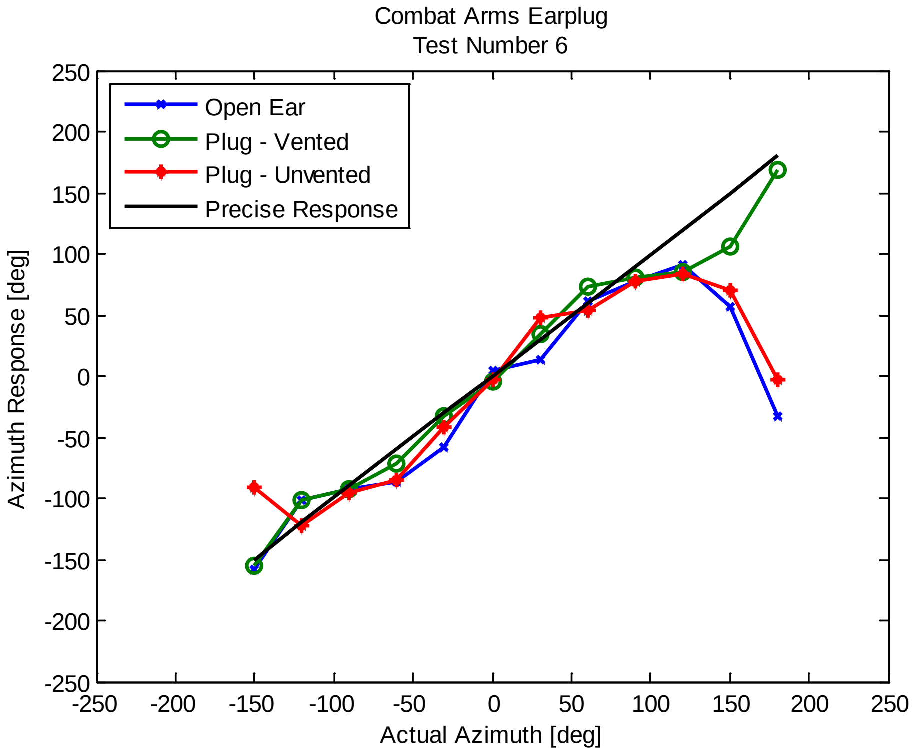

Figure B-16. Combat Arms Earplug™ localization test 6 results.

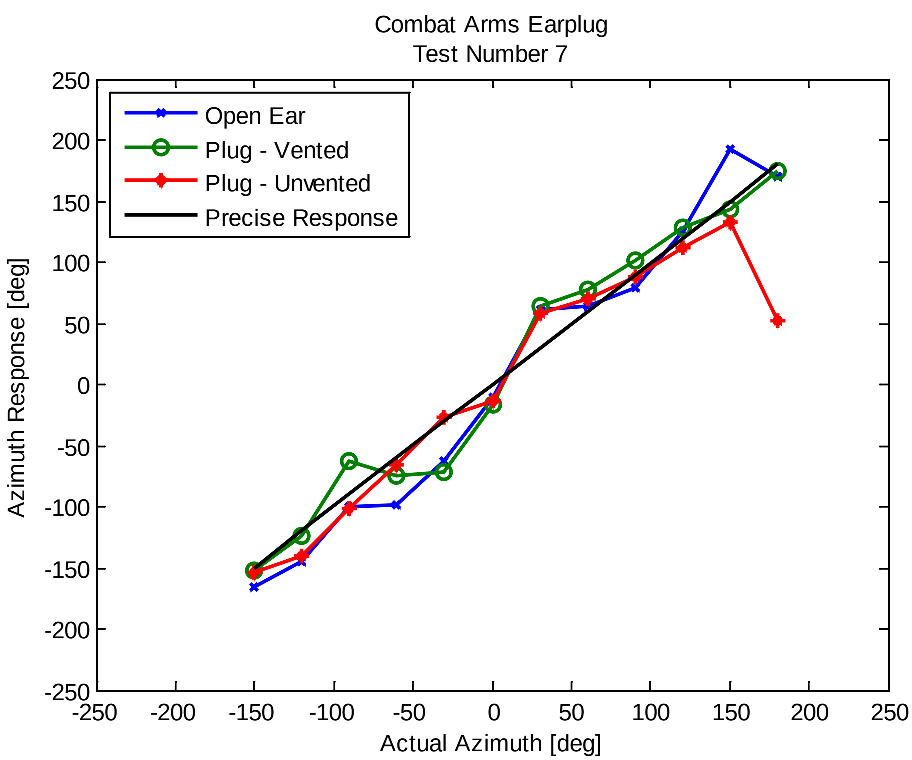

Figure B-17. Combat Arms Earplug™ localization test 7 results.

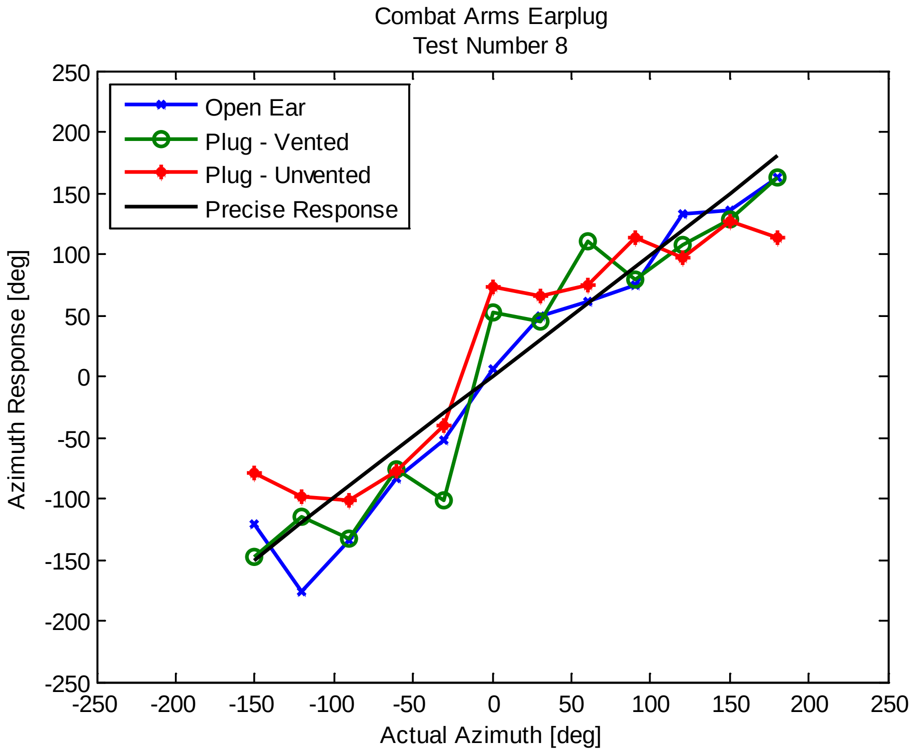

Figure B-18. Combat Arms Earplug™ localization test 8 results.

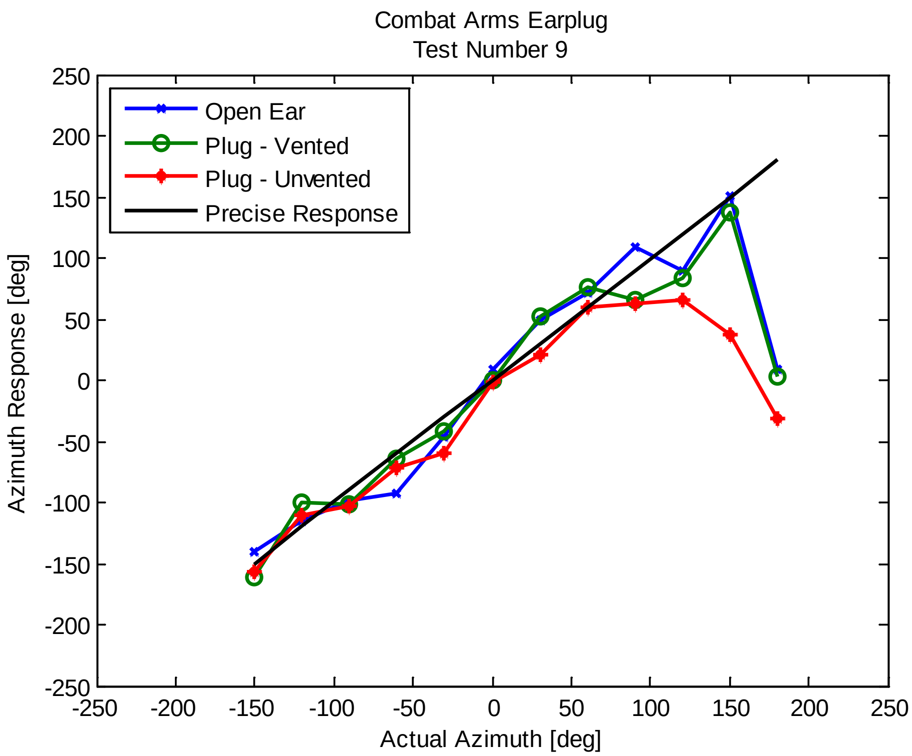

Figure B-19. Combat Arms Earplug™ localization test 9 results.

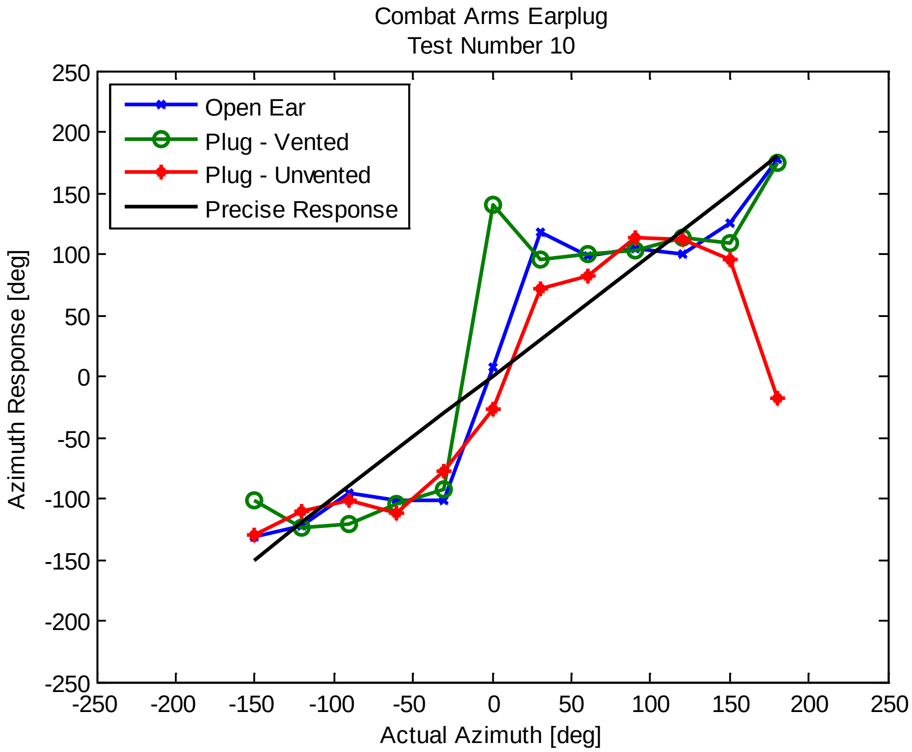

Figure B-20. Combat Arms Earplug™ localization test 10 results.

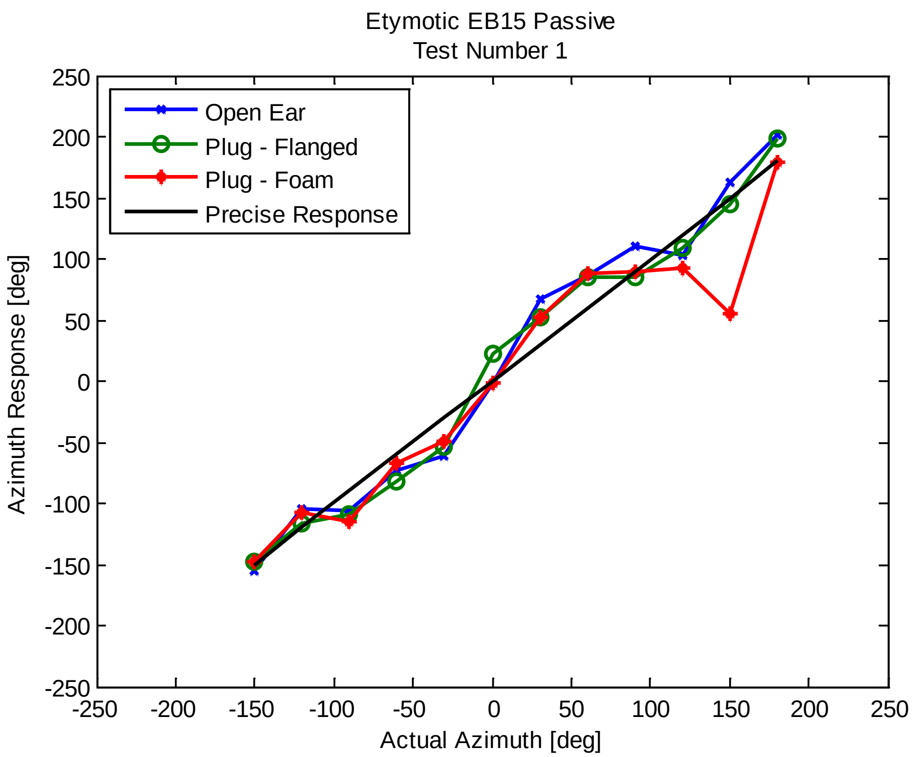

Figure B-21. EB-15 localization test 1 results.

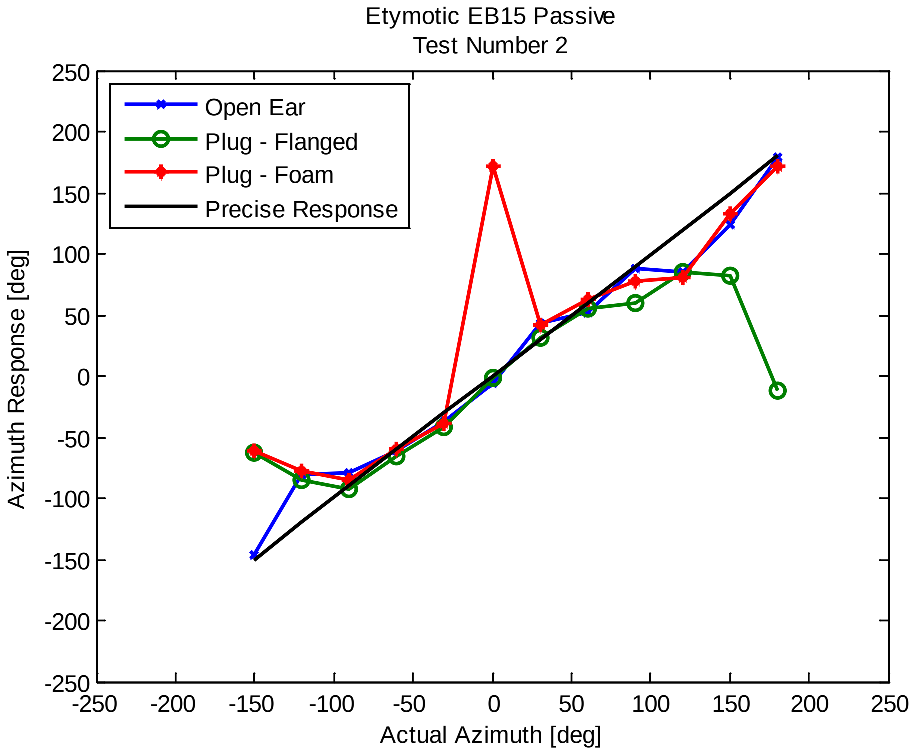

Figure B-22. EB-15 localization test 2 results.

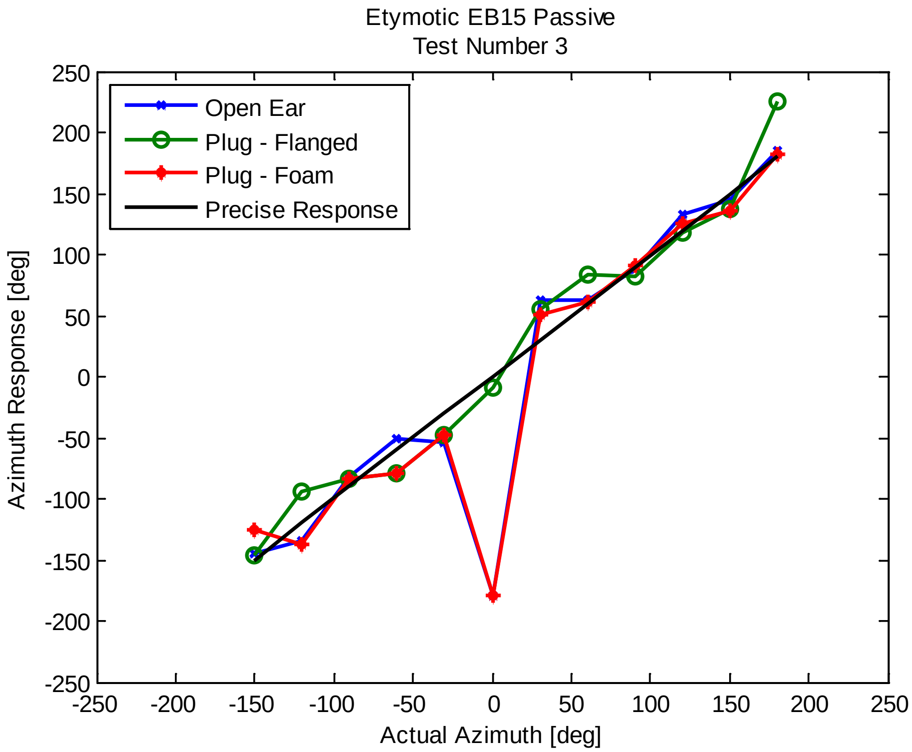

Figure B-23. EB-15 localization test 3 results.

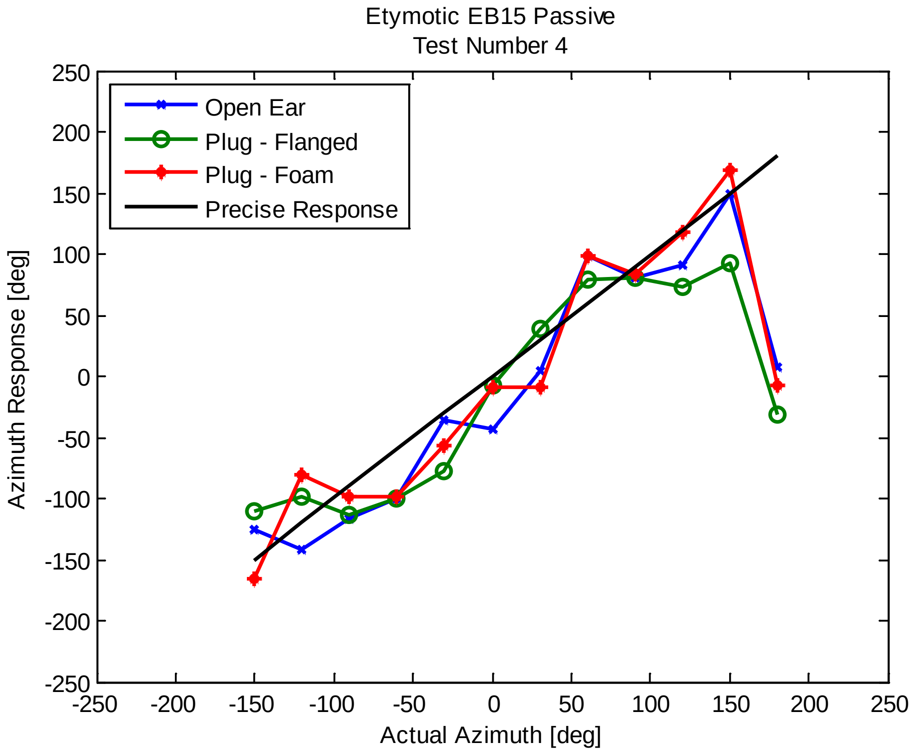

Figure B-24. EB-15 localization test 4 results.

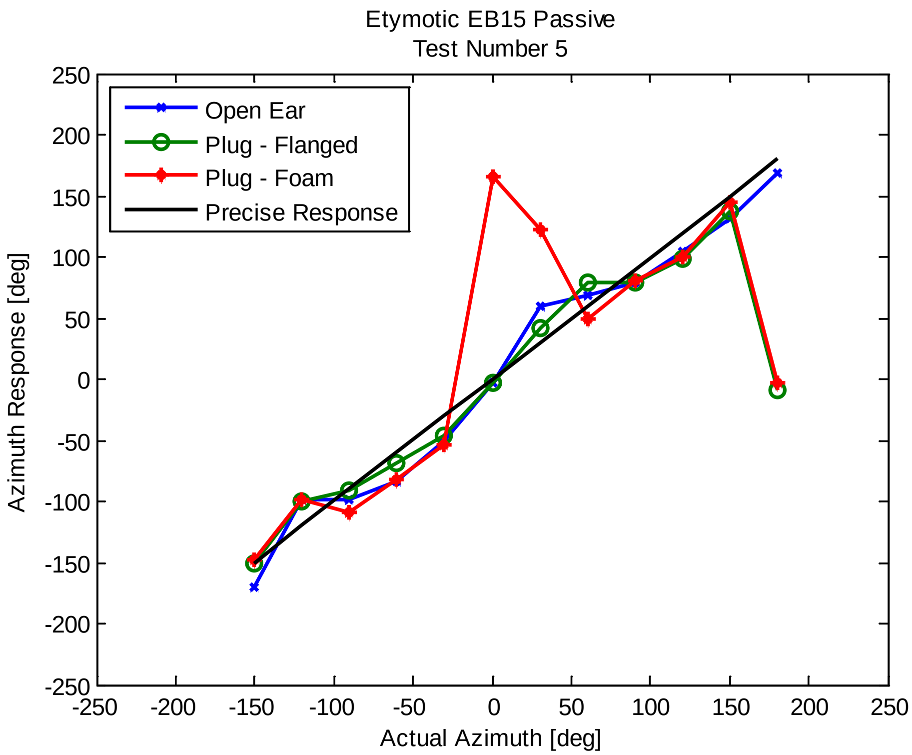

Figure B-25. EB-15 localization test 5 results.

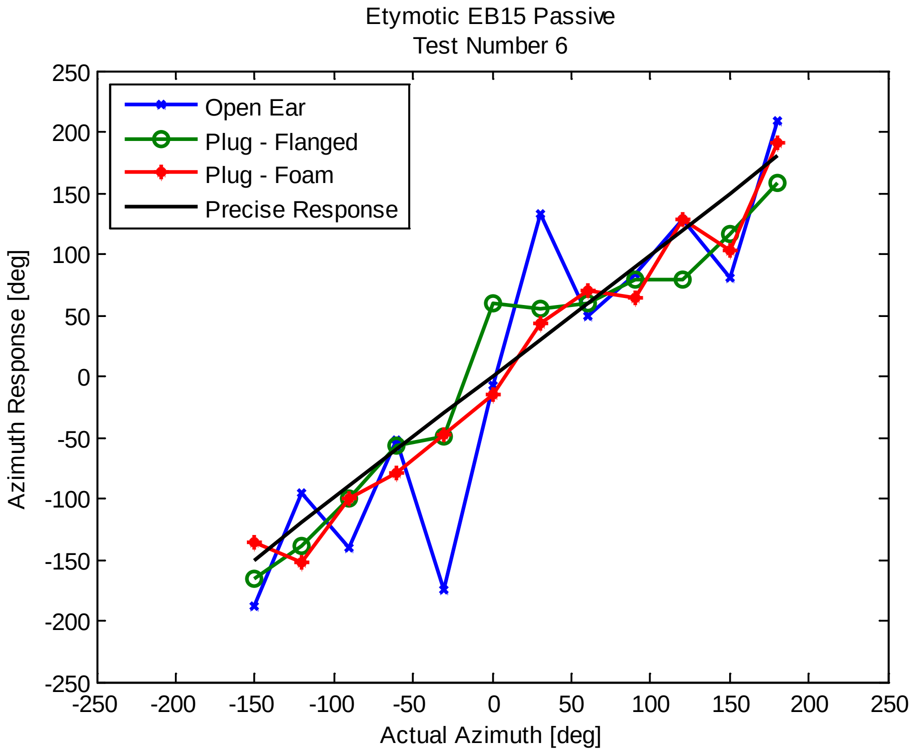

Figure B-26. EB-15 localization test 6 results.

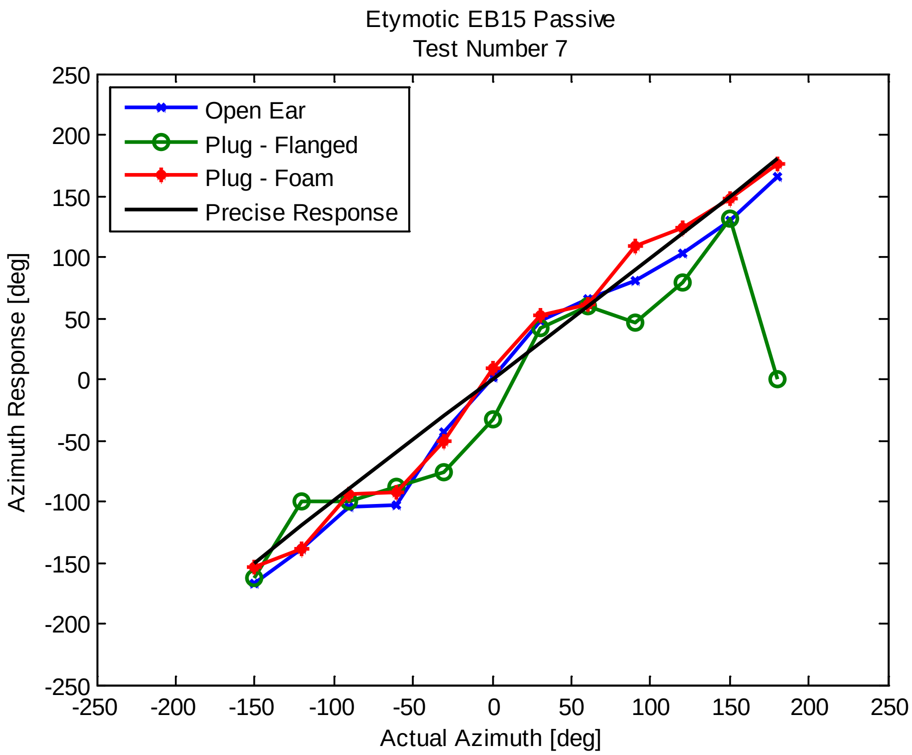

Figure B-27. EB-15 localization test 7 results.

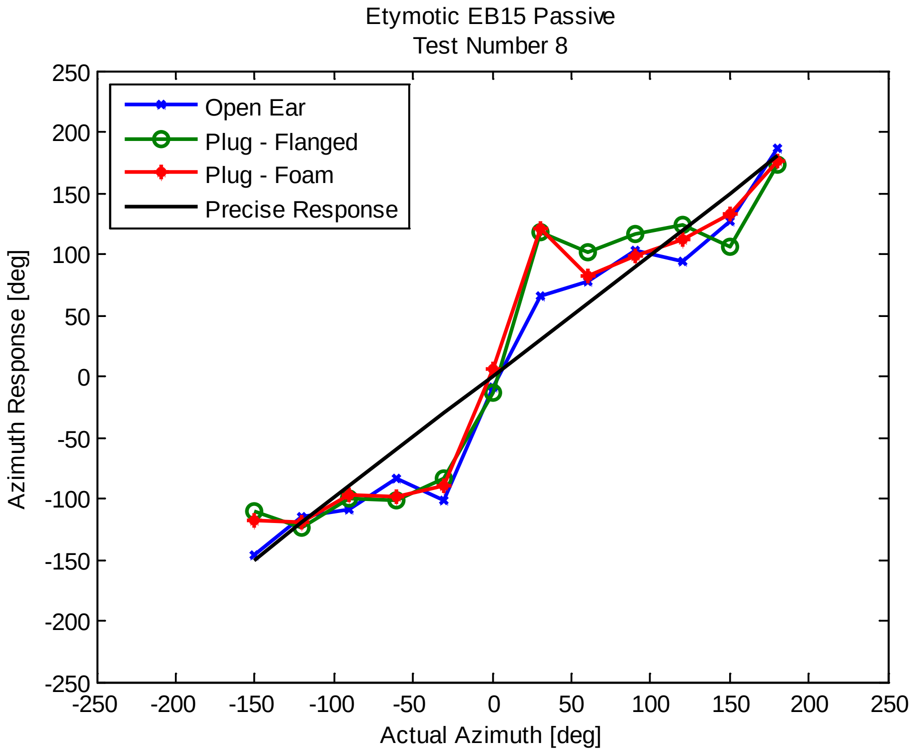

Figure B-28. EB-15 localization test 8 results.

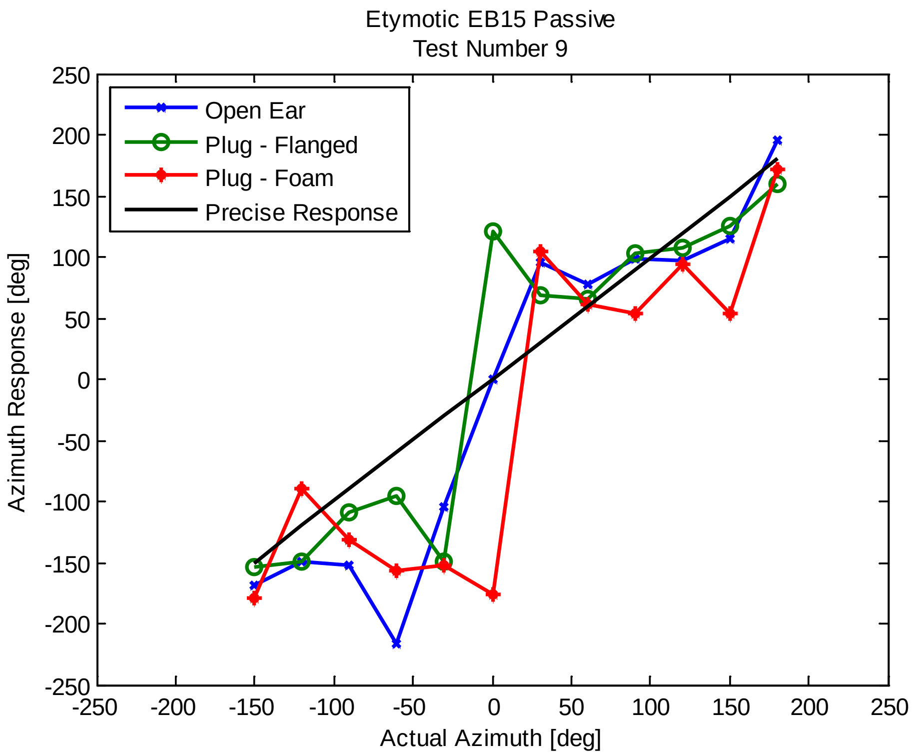

Figure B-29. EB-15 localization test 9 results.

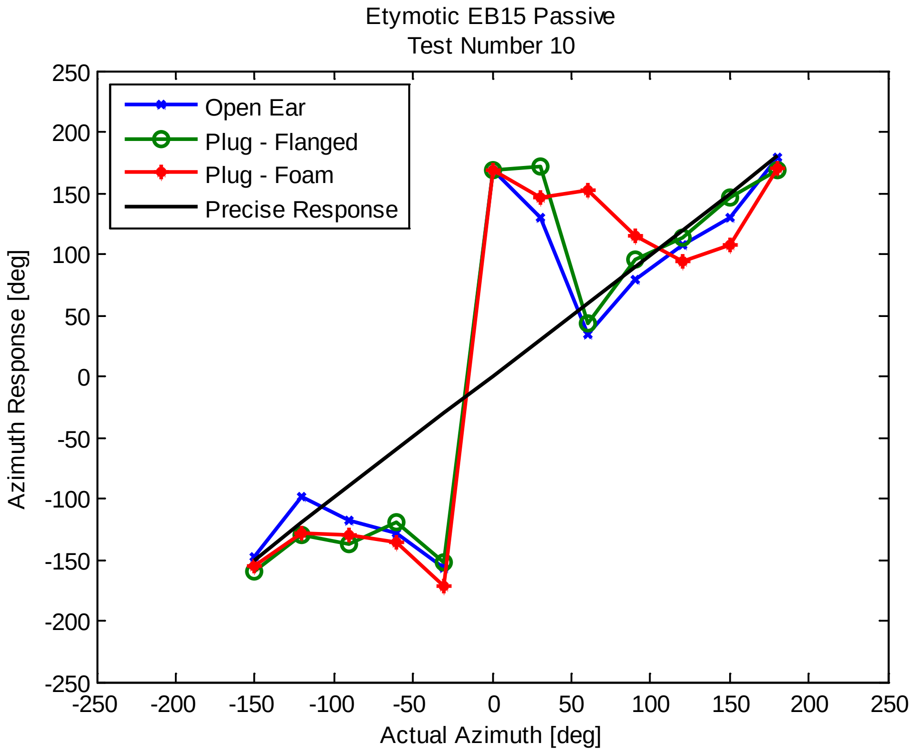

Figure B-30. EB-15 localization test 10 results.

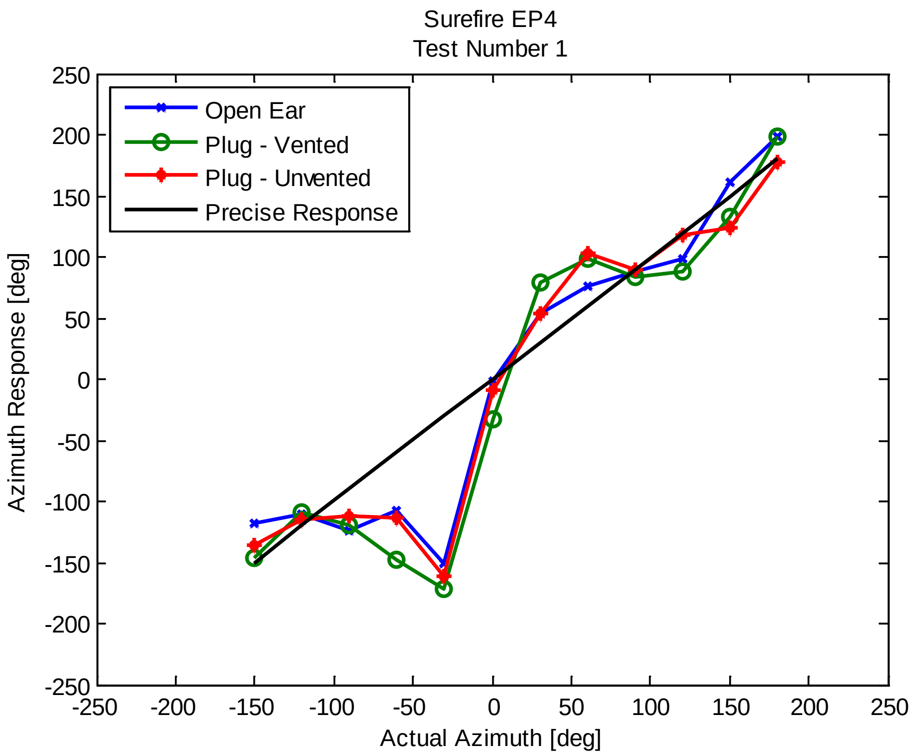

Figure B-31. Surefire EP4® localization test 1 results.

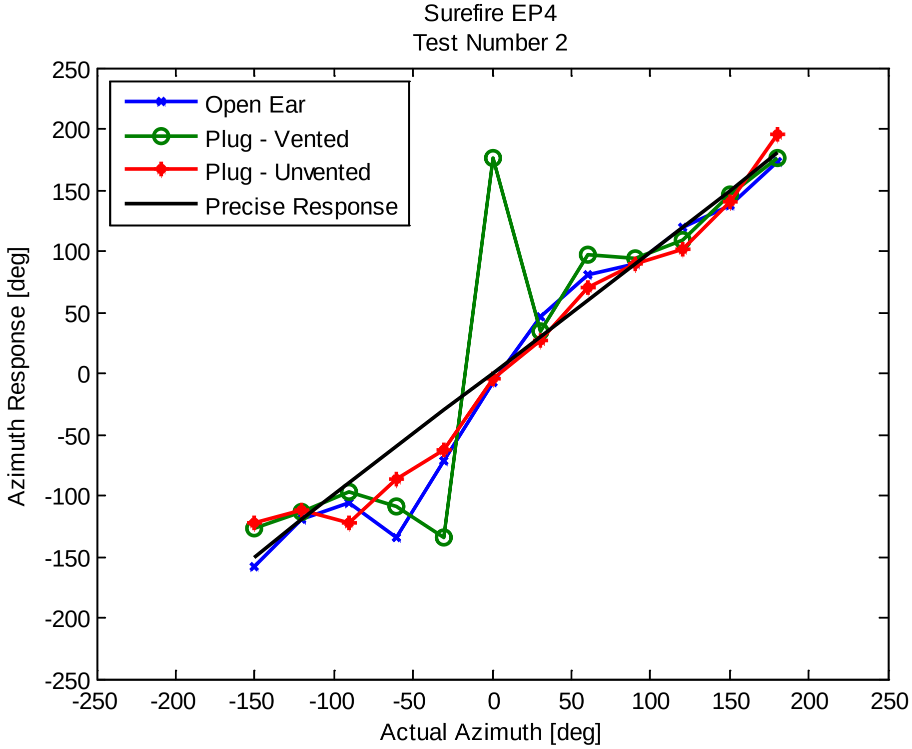

Figure B-32. Surefire EP4® localization test 2 results.

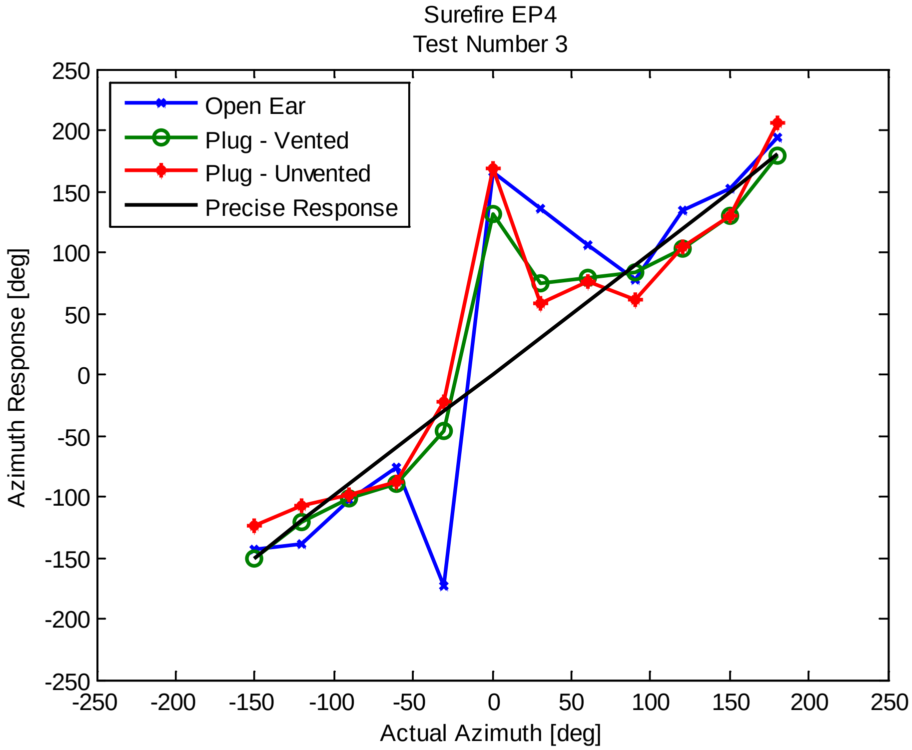

Figure B-33. Surefire EP4® localization test 3 results.

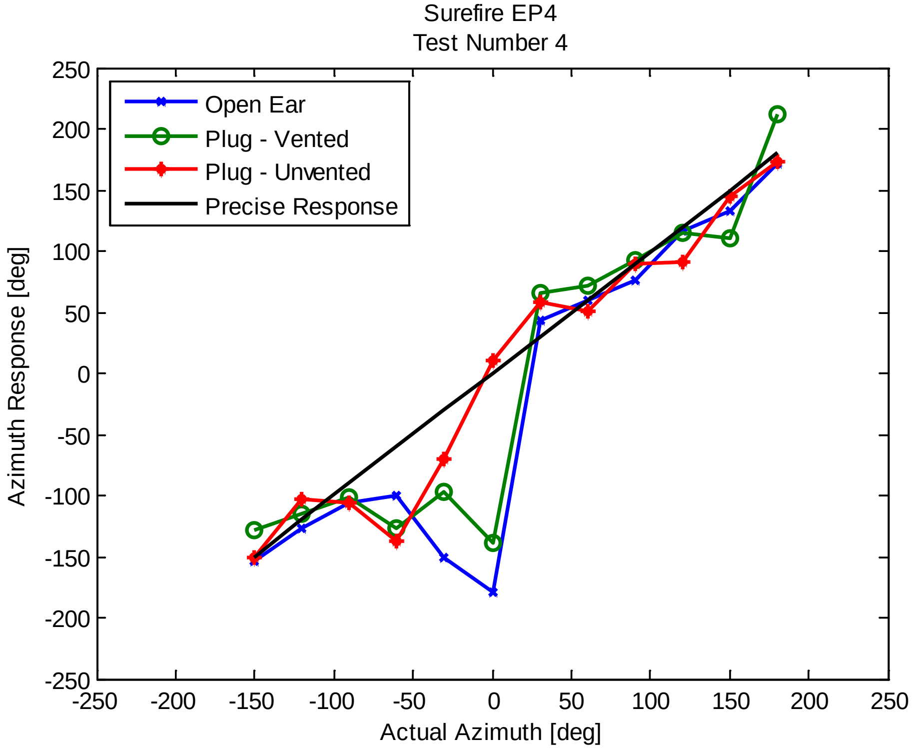

Figure B-34. Surefire EP4® localization test 4 results.

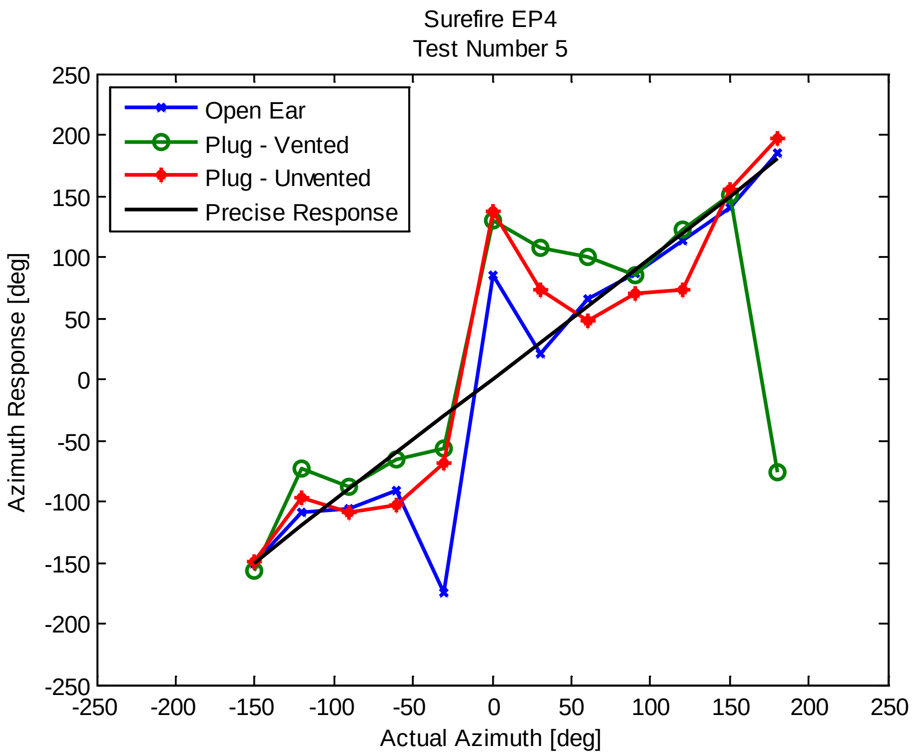

Figure B-35. Surefire EP4® localization test 5 results.

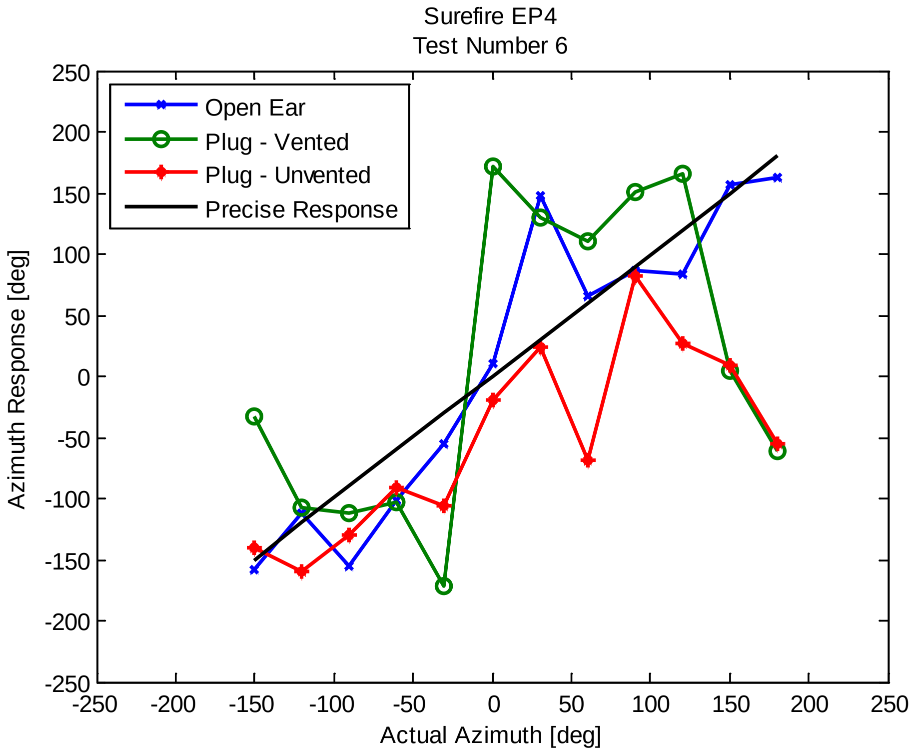

Figure B-36. Surefire EP4® localization test 6 results.

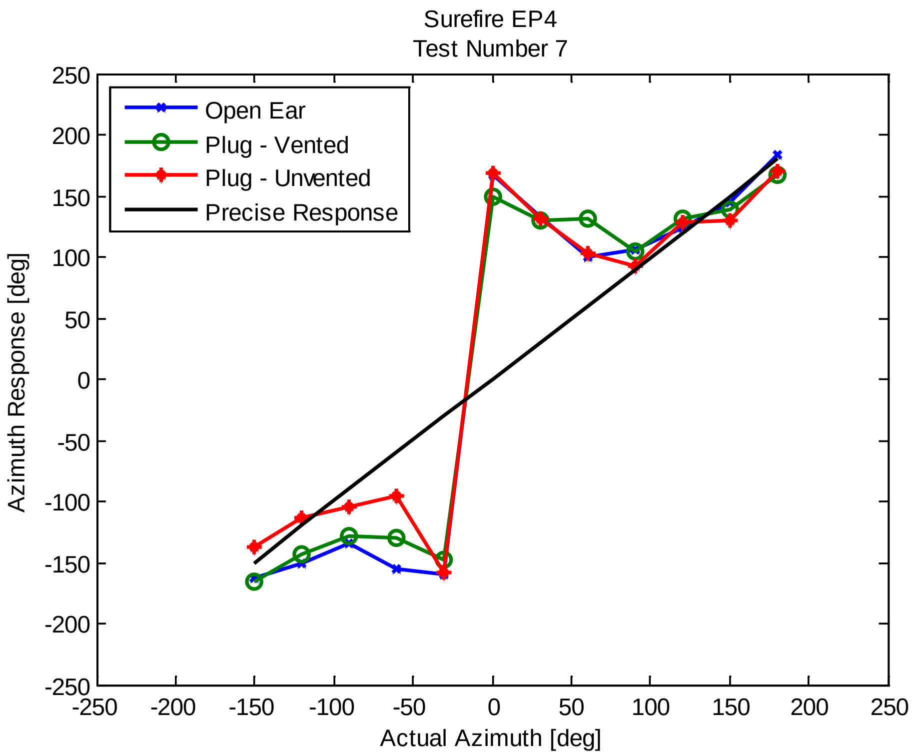

Figure B-37. Surefire EP4® localization test 7 results.

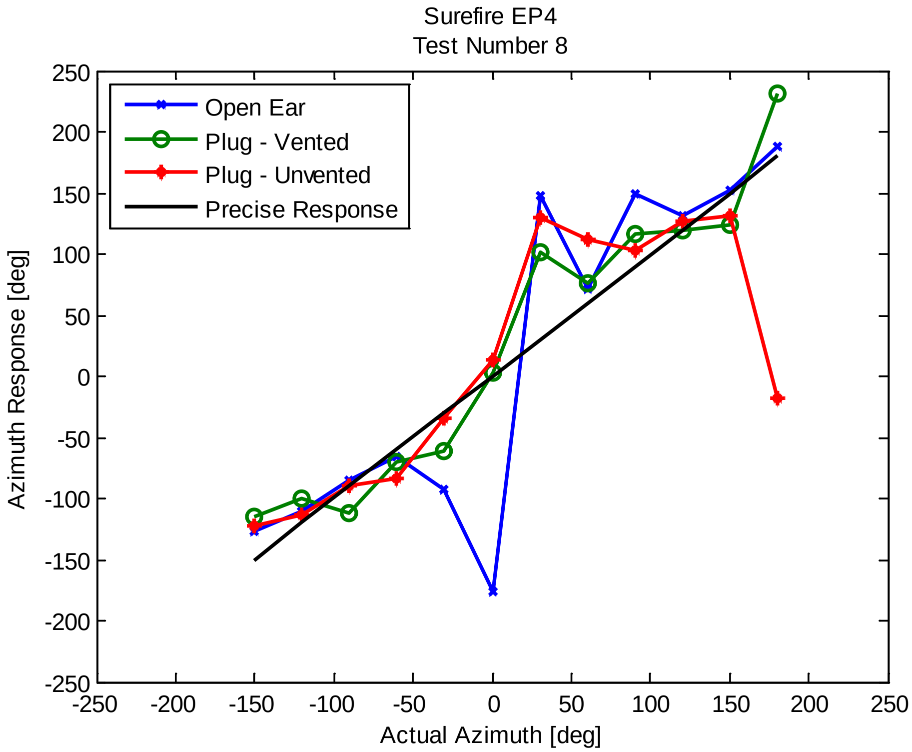

Figure B-38. Surefire EP4® localization test 8 results.

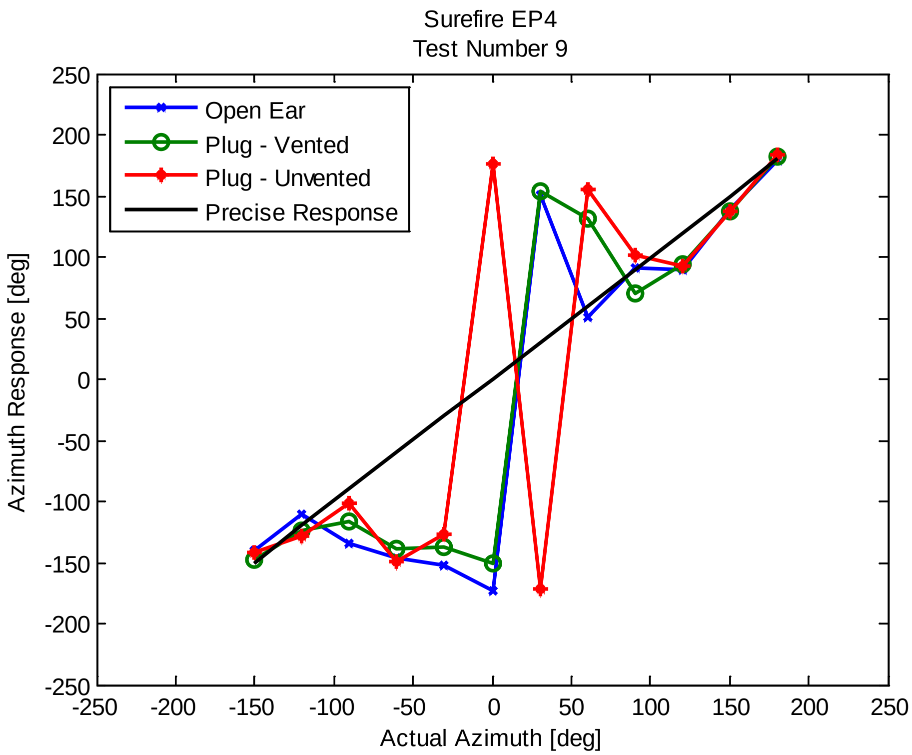

Figure B-39. Surefire EP4® localization test 9 results.

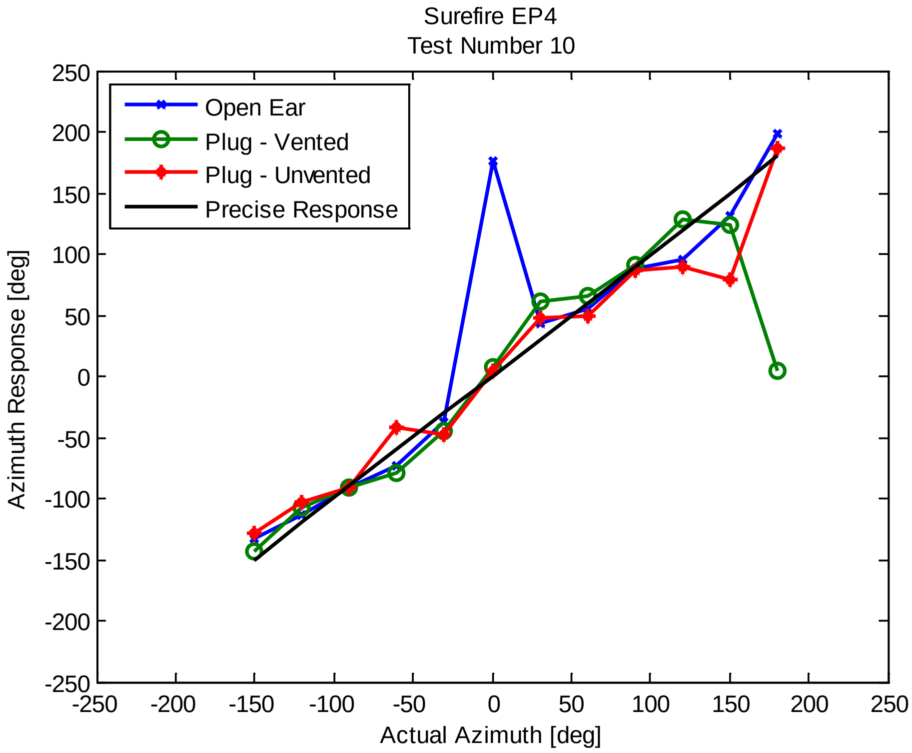

Figure B-40. Surefire EP4® localization test 10 results.

Department of the Army
U.S. Army Aeromedical Research Laboratory
Fort Rucker, Alabama, 36362-0577
www.usaarl.army.mil

U.S. Army Medical Research and Materiel Command